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Municipal and Commercial Equipment for Radiological Response and Recovery in an Urban Environment: State of Science, Research Needs, and Evaluation of Implementation towards Critical Infrastructure Resilience

Nuclear Engineering Division

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Municipal and Commercial Equipment for Radiological Response and Recovery in an Urban Environment: State of Science, Research Needs, and Evaluation of Implementation towards Critical Infrastructure Resilience

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ACRONYMS AND ABBREVIATIONS

ALARA	As Low As Reasonably Achievable
BE	Bench-scale Experiments. Includes bench- and laboratory-scale experiments and computer modeling.
COTS	Commercial Off the Shelf
DHS	U.S. Department of Homeland Security
DOD	U.S. Department of Defense
DIY	Do-It-Yourself
EPA	Environmental Protection Agency
EPD	Electronic Personal Dosimeters
FD	Fire Department
FRMAC	Federal Radiological Monitoring and Assessment Center
GCS	Grand Central Station
GIS	Geographic Information System
GPS	Global Positioning System
HP	Health Physicist
HEPA	High-Efficiency Particulate Air
HVAC	Heating, ventilation, and air conditioning
IBC	Intermediate Bulk Container
LR	Literature Review. Includes literature study, information gathering from subject-matter experts, or other paper studies.
MTA	Metropolitan Transportation Authority
MWRD	Metropolitan Water Reclamation District
NaI	Sodium Iodide
NVQ	National Vocational Qualification
NY	New York
OCWD	Orange County Water District
Off spec	Off Specification

PPE	Personal Protective Equipment
PD	Police Department
PE	Pilot-scale Experiments. Includes pilot- or large-scale experiments and demonstrations.
PTT	Push-To-Talk
QA/QC	Quality Assurance/Quality Control
R5	EPA Region 5
RAP	Radiological Assistance Programs
ROSS	Radiological Operations Support Specialist
R&D	Research and Development
RO	Reverse Osmosis
SME	Subject-Matter Expert
SQEP	Suitably Qualified and Experienced Person
TLD	Thermoluminescent Dose Meters
UK	United Kingdom
USB	Universal Serial Bus
WERF	Water Environment Research Foundation
WMD	Weapons of Mass Destruction

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1 INTRODUCTION

The National Urban Security Technology Laboratory of the U.S. Department of Homeland Security (DHS), in collaboration with the U.S. Environmental Protection Agency's (EPA) National Homeland Security Research Center and Argonne National Laboratory, seeks to identify equipment that support methods to mitigate the effects of a radiological or nuclear release in the urban environment. This includes understanding the types of equipment that might be available and evaluating the efficacy of such equipment toward a number of potential response and recovery goals including monitoring, containing, and decontaminating contaminated structures, vehicles, and materials.

During the immediate, emergency phase of a response, it will be impossible to initiate activities other than establishing life-saving operations and securing a site for the safety of the public and first responders. This project is concerned with the period between securing of the site and the beginning of a federally organized cleanup effort. This period might be significant, as we have learned from the Japanese and their response time for the disaster at Fukushima. Processes and procedures for a timely response to a wide-area contamination event are not currently established around the country. Response planning of this type is still in the very early stages, and this project is part of this work.

This project focused on connecting with relevant emergency management and homeland security offices at the city, state, and regional level, including major cities across the United States, and with federal agencies. Within these offices, we consulted with subject matter experts (SMEs) and also evaluated commercial-off-the-shelf products. The result was a compilation and assessment of approaches to address potential contamination scenarios and the types of equipment assets that would or could assist in the response and recovery effort. We also documented what recommendations the SMEs suggested on how current equipment reserves can be best used or modified to improve their utility in radiological or nuclear mitigation.

This report contains a comprehensive list of proposed equipment to accomplish various missions or scenarios that might arise after a large-scale radiological contamination incident in an urban environment. Preliminary information was published in separate reports, *Subject Matter Expert Workshop for the Use of Municipal and Commercial Equipment for Radiological Response and Recovery Summary Report: Argonne National Laboratory* (ANL/NE-17/35) and *Subject Matter Expert Workshop for the Use of Municipal and Commercial Equipment for Radiological Response and Recovery Summary Report: National Urban Security Technology Laboratory* (ANL/NE-17/36). We attempted to include all relevant SMEs, stakeholders, and information resources. However, we recognize that gaps remain in our knowledge because regions vary in capabilities and assets, and input was missing from specific experts who were unable to attend and could not be reached for comment. We list these information gaps in Table 2-1. Moreover, we recognize that existing guidance and technical documents are already available for certain situations. Some examples are provided in Section 5, Existing Guidance, although this listing is not meant to be exhaustive.

Potential response and recovery efforts were divided into five support goals (see tables in Section 3). The five support goals were as follows:

- Survey and monitoring of the contaminated area;

- Mitigation of received dose to first responders;

- Decontamination (gross and final) of buildings, vehicles, roadways, parks, and other surfaces;

- Waste management of solid waste generated during recovery operations; and

- Containment of wastewater and other waste generated during the response and recovery phases.

Within each support goal, we define several missions or scenarios that describe specific situations that require a response activity. Within each support goal sheet, next to each scenario, we summarize the general techniques and equipment suggested by the SMEs and our information gathering activities. For each piece of equipment, we briefly describe its proposed function, its advantages, and the potential limitations in its use, our knowledge of its function, or its efficacy to accomplish the task proposed in the scenario. Finally, we summarize the general research and development (R&D) needs for items. These are further categorized as literature review (LR), bench-scale experiment (BE), and pilot-scale experiments (PE):

- LR—literature review. Includes literature study, information gathering from subject-matter experts, or other paper studies.

- BE—bench-scale experiment. Includes bench- and laboratory-scale experiments and computer modeling.

- PE—pilot-scale experiment. Includes pilot- or large-scale experiments and demonstrations.

The information from Tables 3-1-1 to 3-5-8 was disseminated to SMEs so they could rank equipment and/or technologies that might have the most impact and could benefit from future work to better understand its efficacy. This future work may include the development of best-practice guides, as well as laboratory and/or field-testing of municipal equipment. From their responses, we identified those equipment and technologies ranked highest (Section 4).

Another aspect of this report is to address the five support goals considering the potential needs of critical infrastructure. Critical infrastructures (e.g., government, health care, school, transportation, energy, communication, etc.) in the contaminated area must be restored quickly to minimize both direct and indirect impacts. For example, wide area contamination may pose a direct impact to the local community due to health impacts and denial of services, including possible relocation. Surrounding communities may also be affected indirectly by inhibiting people who travel to the community for work or personal activities or rely on services from the directly impacted area. Rapid decontamination methods will be needed for critical infrastructure to enable their continuous operation. This report provides a brief description of various critical infrastructure and information gathered on mitigating the effects of contamination.

2 GENERAL KNOWLEDGE GAPS AND EXISTING GUIDANCE DOCUMENTS

This project identified common gaps across most or all of the support goals for use of equipment to accomplish various missions or scenarios that might arise after a large-scale radiological contamination incident in an urban environment (Table 2-1). We identified these gaps after reviewing the information gathered from various activities. These activities included two workshops attended by various local, state, regional, and federal agencies and by SMEs in the areas of response/recovery and management of equipment and personnel assets; telephone conversations; personal meetings; and feedback with SMEs. We attempted to include all the relevant SMEs and stakeholders and review pertinent documents. However, we recognize that gaps remain in our knowledge because of local, state, and regional variance in capabilities and assets, missing input from specific experts who were unable to attend or could not be reached for comment, and uncertainties in the performance of equipment for off-spec activities. Gaps specific to the use of a particular piece of equipment or technology and opportunities for R&D are provided in Tables 3-1-1 through 3-5-8.

TABLE 2-1 Common Limitations in Our Ability to Use the Equipment/Technology for Its Proposed Purpose or Lack of Knowledge about Its Efficacy.

Topic	Description of General Overarching Needs
Critical Infrastructure	• The predicted effects of contamination on critical infrastructure need to be assessed (e.g., fate and transport of contaminant, exposure potential for public and workers). Methods of decontamination need to be assessed. Guidance on use of measurement instruments specific to critical infrastructure and geographic information system (GIS) integration of some of the equipment listed will be necessary. • Key input is missing regarding capabilities and assets available to critical infrastructure that includes local, state, and regional variations. This includes but is not limited to infrastructure associated with drinking water supply and distribution networks, wastewater treatment, sewers, tunnels and bridges, transportation/highway authority, airport authority, ports, fleet and facility management, hospitals, energy (electricity, natural gas, fuel), and communication centers.
Data Sharing	• During a response and recovery effort, data may be gathered from response teams and then handed over to recovery teams. The data might be further distributed to state and local agencies. Each agency may have different platforms for data management, and the visualizations they generate to communicate with the public might be confusing. The data (i.e., data management platforms and GIS integration) need to be compatible between agencies and reconcile issues related to quality assurance/quality control (QA/QC).

TABLE 2-1 (Cont.)

Topic	Description of General Overarching Needs
GIS Integration	• Although many agencies use GIS platforms, all systems may not be compatible with each other. Therefore, data gathered during the response and recovery effort needs to be made compatible with existing GIS data management systems. • The U.S. Department of Defense (DOD) used GIS integration during the responses to Hurricane Sandy and other natural disasters through their joint task force–civil support teams. Discussions of DOD capabilities are needed to better understand the challenges associated with integrating various GIS platforms during a recovery effort. .
Data to Support Off-Spec Use	• There is not much data on radioactive contamination or surrogates that mimic the physico-chemical characteristics of radioactive fallout contamination. Surrogate fallout material that properly represents the potential characteristics of urban contamination needs to be developed so that R&D tests can produce the most realistic outcomes for accurate guidance. • Many of the equipment and technology listed in Tables 3-1-1 to 3-5-8 have familiar operations but a radiological event often will require off-spec use. Guidance needs to be provided to ensure effective operation and to identify the factors that control the efficacy of the proposed equipment usage. This includes, for example, how much soil to remove, how best to wipe or wash a surface, where to place personal monitoring devices, how much water is best to optimize removal of contaminants from vehicles or structures, how many times a surface should be treated, how thick to apply coatings, etc. • All equipment proposed may or may not be available during the early and intermediate phases of recovery because they may have existing private commitments, owners may refuse to contribute their equipment and skills, or the equipment may or may not be able to return to duty following decontamination (either poor decontamination factors or due to regulatory or legal issues). It may be critically important to model the logistical procurement and movement of equipment and personnel assets under conditions proposed here to properly understand the timeline for response and recovery efforts. • An unresolved issue is that common mechanical equipment that might be used for radiological work is not typically supplied with sealed cabs and high-efficiency particulate air (HEPA) filtration. Therefore, operator personal protective equipment (PPE) needs to be addressed and equipment may need to be modified prior to use. • All equipment associated with detection of radiation levels must be evaluated for detection sensitivity in the expected environment as described in the scenarios (e.g., outdoor, in a persistent and abnormal radiation background). • Methods of interrogating large storage containers need to be identified and developed so responders can determine radionuclide content. This need includes both solid waste and liquid waste containers (bags, totes, tanks, tanker vehicles, etc.).

TABLE 2-1 (Cont.)

Topic	Description of General Overarching Needs
Data to Support Off-Spec Use (Cont.)	• For do-it-yourself (DIY) equipment,[1] best practices guidance is not available. Such guidance would need to be published to reduce risk and improve efficacy.
Training	• Rules and regulations related to transporting potentially-contaminated materials in vehicles not licensed for such use need to be reviewed. • PPE requirements need to be established for handling potentially radioactive materials. • It may be difficult to maintain QA/QC of data that originate from untrained or insufficiently trained populace. GIS integration may be difficult for equipment used for detection/tracking. • Radiological Operations Support Specialists (ROSSs) are specially trained health physicists who have detailed knowledge of what to do during a nuclear emergency. It might be possible to augment ROSS training to include the training needs described in Tables 3-1-1 through 3-5-8.
Regulations and Cost-Benefit Analysis	• Stakeholders need to agree upon siting locations for collection, handling, storage, and disposal of waste before an event takes place. • Guidance is needed about how to predetermine potential waste or asset staging locations so that they meet safety requirements and stakeholder approval. • The relative benefits of all techniques that introduce secondary waste (e.g., water; dry solids such as sand, gravel, asphalt; coatings such as polymers and tar) need to be assessed to take into account the additional radioactive waste they might produce.

[1] DIY may include equipment and techniques that may be used by individual homeowners or volunteer cleanup teams.

3 SUPPORT GOALS AND SCENARIOS EQUIPMENT/TECHNOLOGY INFORMATION

This section describes the five support goals and the scenarios posed within them. Tables 3-1-1 through 3-5-8 summarize the equipment and technologies proposed for various activities that might arise after a large-scale radiological contamination incident in an urban environment. Also, briefly described are the perceived advantages and known limitations of each and the suggested research and development needed to support the proposed use of the equipment or technology. These suggested needs are broadly categorized as literature reviews (LR) of existing documents, studies, or consultation with subject matter experts (SME), benchtop experiments (BE), and pilot-scale experiments (PE). It is expected that following these types of studies, sufficient data to develop specific guidance on the use of the equipment or technology and estimated efficacy for the proposed activities would be collected. Further, general observations were raised by the SMEs during the gathering of this information, and these ideas are captured either in the summary section of each table or in the last two rows of each table.

3.1 SUPPORT GOAL: SURVEY AND MONITORING

Contamination levels in affected areas need to be monitored, perhaps for an extended time, to understand the radiation dose to workers and residents and the evolving levels of contamination level over time. What types of municipal and commercial equipment can enhance surveys and monitoring of contamination? (Note that traditional survey monitoring equipment such as film badges, portable survey monitors, and gamma-ray spectrometers already in place with response vehicles or personnel will not be assessed because these are specialized pieces of equipment that are already accounted in the first responders' procedures.) Examples include measuring contamination in air filters from garbage trucks, delivery trucks, police cars, and firetrucks that have well-defined routes. These vehicles can be tracked using global positioning system (GPS) monitoring to understand the spatial distribution of airborne contamination, or traditional survey equipment can be attached to other vehicles that have well-defined routes. Tables 3-1-1 to 3-1-8 present scenarios related to survey and monitoring, possible responses to the scenarios, and possible equipment/technology used in responding, including its advantages, limitations, and R&D needs.

TABLE 3-1-1 Support Goal: Survey and Monitoring for Scenario 1

Scenario Description	Summary	Category	Column Number							
			1	2	3	4	5	6	7	8
Scenario 1: Measure, on a regular basis, the contamination levels in areas initially affected by radioactive contamination (fallout deposits of radioactive material) in terms of **external dose at the street level** (the radiation levels at the street from external gamma and beta radiation). What equipment can provide such measurements? What tools are available to develop maps of contamination with this data?	• Many of these items are currently part of the first-responders' toolkits and various radiation response plans [e.g., local fire departments (FD) and police departments (PD), Radiological Assistance Programs (RAP), Federal Radiological Monitoring and Assessment Center (FRMAC) or equipment common to a nuclear power station or radiological laboratories such as at universities and hospitals] (See *Planning Guidance for Response to a Nuclear Detonation*, FEMA, June 2010). • Data collection and mapping software exists (e.g., ESRI ArcGIS Operations Dashboard and Collector apps). • Several companies produce systems for wide-area monitoring, but most likely do not satisfy the following requirements: ○ Measurement of beta radiation and neutrons, ○ Common data format, ○ Wireless remote upload of data. • This scenario may require the following: ○ Small, agile vehicle capable of covering areas required quickly. ○ Detector(s) that provide a dose rate with beta/gamma differentiation. ○ Automatic data logging of dose rates, location, date/time, and instrument. ○ Error checking. ○ Easy operation: low-skill operator. ○ Common data format: compatible with GIS/analysis software. ○ Wireless remote upload of data to control station. ○ Database for results. ○ GIS/maps with data overlay. ○ Ability to easily (visually) interpret and compare data over time. • Local agencies may complete mapping for radiation levels because they may have the vehicles with mounted detectors. • TLDs on bus routes, animals, and other locations could build a picture of contamination in an area. It would be worth considering lower fidelity and higher standard validation techniques that can be used together (e.g., smart phones or personal detection devices). People could use a universal serial bus (USB) dosimeter to track their own dose and feed it to a central database.	EQUIPMENT	Smart phone radiation detectors.	Thermoluminescent dose meters (TLDs).	Electronic personal dosimeters (EPDs).	Electronic data logging.	Two-dimensional (2D) mapping gamma camera.	Vehicle-mounted large-aperture detectors (e.g., NaI).	Manned, detailed measurement surveys.	Small, agile vehicle.
		DESCRIPTION	Detects radiation with a metal-oxide semiconductor chip. 	Measures beta and gamma doses at fixed or mobile locations. 	Measures gamma doses at a range of fixed or mobile locations. 	Provides continuous gamma and neutron monitoring using sodium iodide (NaI) detector. 	Identifies hotspots in a general radiation field. May be able to produce a 3-D rendering of work area. 	Mobile detectors for mapping contamination. 	Portable instruments for trained operators. 	Ground-based or aerial vehicles outfitted with detectors. 
		ADVANTAGES	Existing network of phones, mobile.	Large numbers commercial-off-the-shelf (COTS), low cost, fixed or mobile usage.	Large numbers COTS, low cost, fixed or mobile usage, large sensitivity range (0.1 µSv/h to 10 Sv/h).	COTS, large sensitivity range (0.1 µSv/h to 10 Sv/h), fixed or mobile usage.	Fixed or mobile, hotspot identification (ID), isotopic ID.	GIS integrated, fixed or mobile, isotopic ID.	Large numbers COTS, mobile.	Mobile, large coverage rate.
		LIMITATIONS	QA/QC, high threshold (~10 µSv/h), GIS integration apps, gamma only.	High threshold, not real-time, no GIS integration, beta/gamma but no alpha, limited readers available.	No GIS integration, gamma only.	No GIS integration, not rugged enough for outdoors	Limited quantity available, high threshold, gamma only. Some models may not have GIS integration.	Limited quantity available, gamma only.	No GIS integration, significant manpower, background radiation interference, access to private premises.	Available numbers, GIS integration, skilled operators.
		R&D NEEDS	Guidance on use (LR). Practicality for immature technology (LR, BE). GIS integration tools (LR, BE).	Guidance on use (LR). Integrate lower fidelity and higher standard validation techniques (e.g., smart phones, TLD, or EPD) (LR, BE, PE).	Guidance on use (LR). GIS integration tool (LR, BE).	Guidance on use (LR). GIS integration tool (LR, BE).	Guidance on use (LR). GIS integration tool (LR, BE). Survey of inventory (LR).	Survey of inventory (LR).	Guidance on use (LR). GIS integration tool (LR, BE)	Survey of inventory (LR, BE). Compatible radiation detectors (BE, PE).

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TABLE 3-1-2 Support Goal: Survey and Monitoring for Scenario 2

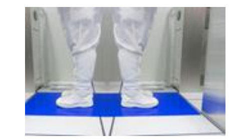
<table>
<tr><th rowspan="2">Scenario Description</th><th rowspan="2">Summary</th><th rowspan="2">Category</th><th colspan="6">Column Number</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td rowspan="5">Scenario 2:
Measure, on a regular basis, the contamination levels in areas initially affected by radioactive contamination (fallout deposits of radioactive material) in terms of external dose within residences and businesses (the radiation levels within homes, apartments, or business offices from external gamma and beta radiations). What equipment can be used to provide such measurement? What tools are available to develop maps of contamination with this data?</td><td rowspan="5">Most SMEs believe that monitoring within homes and individual businesses will be more difficult than external monitoring.
Confidence in the dose data that is disseminated to the public is necessary. For data collected by expert organizations like FRMAC, this is not an issue. However, if we provide detection systems onto people, then we must have confidence in their response.
In some cases, these would represent low-fidelity data. However, this data may represent a very thorough cross-section of the affected environment. Guidance on use and GIS integration of the equipment listed will be necessary.</td><td>EQUIPMENT</td><td>Smart phone radiation detectors.</td><td>Environmental TLDs or EPDs.</td><td>Instadose by MIRION Technologies.</td><td>Manned, detailed measurement surveys.</td><td>Tacky mats for human traffic.</td><td>Two-dimensional (2D) mapping gamma camera.</td></tr>
<tr><td>DESCRIPTION</td><td>Detects radiation with a metal-oxide semiconductor chip.
</td><td>Measures beta and gamma doses at a range of fixed or mobile locations.
</td><td>USB dosimeters to deploy to many types of vehicles, animals, and structures. Can be given to people to track their own dose and send data to a central database.
</td><td>Portable instruments for trained operators.
</td><td>Controls loose contamination at entrances to buildings or rooms.
</td><td>Identifies hotspots in a general radiation field. May be able to produce a 3-D rendering of work area.
The EPA (R5) is working on indoor mapping techniques. Instruments use LIDAR to view and map interiors with attached radiation equipment.
</td></tr>
<tr><td>ADVANTAGES</td><td>Existing network of phones.</td><td>Large numbers COTS, low cost, fixed or mobile usage.</td><td>Cheap enough to deploy.</td><td>Large numbers COTS.</td><td>Different sizes and colors, low cost, large numbers COTS.</td><td>Fixed or mobile, hotspot ID, isotopic identification.</td></tr>
<tr><td>LIMITATIONS</td><td>QA/QC, high threshold (~10 μSv/h), GIS integration apps, gamma only.</td><td>High threshold, not real-time, no GIS integration, beta/gamma but no alpha, limited readers.</td><td>No GIS integration, not rugged for outdoors.</td><td>No GIS integration, manpower, background radiation interference, ruggedness, access to private premises.</td><td>Handling and disposal.</td><td>Limited quantity available, high threshold, γ only. Some models may not have GIS integration.</td></tr>
<tr><td>R&D NEEDS</td><td>Guidance on use (LR). Practicality for immature technology (LR, BE). GIS integration tools (LR, BE).</td><td>Guidance on use (LR). Integrate lower fidelity and higher standard validation techniques (e.g., smart phones, TLD, or EPD) (LR, BE, PE).</td><td>Guidance on use (LR). GIS integration tools (LR, BE).</td><td>Guidance on use (LR). GIS integration tools (LR, BE)</td><td>Best practice guidance (LR). Removal efficiency testing (BE).</td><td>Guidance on use (LR). GIS integration tool (LR, BE). Survey of inventory (LR).</td></tr>
</table>

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TABLE 3-1-3 Support Goal: Survey and Monitoring for Scenario 3

Scenario Description	Summary	Category	Column Number						
			1	2	3	4	5	6	7
Scenario 3: In the areas affected by contamination, measure, on a regular basis the **re-suspended contamination levels at the street level** (the contamination attached to airborne particles that are suspended in the air as a result of vehicle travel, pedestrian travel, or wind). What equipment can be used to provide such measurement? What tools are available to develop maps of contamination with this data?	• Guidance on use in different situations and GIS integration of the equipment listed will be necessary. Examples of municipal equipment that could serve as a platform for measurement of contamination include buses, postal vehicles, sanitization trucks, and snow removal trucks because they already use tools (e.g., apps) that track their movement. However, the SMEs cautioned that any sensor affixed to a vehicle must have a validated QA/QC protocol. • It may be useful to use the interfaces, maps, and existing apps and couple them with radiation detection devices and the Rad Responder Network (https://www.radresponder.net/). • Filter efficiency for radioactive particles will need to be determined for several of the filters listed. • TLDs on bus routes, animals, and other locations could build a picture of contamination in an area. It would be worth considering lower fidelity and higher standard validation techniques that can be used together (e.g., smart phones or personal detection devices). People could use a universal serial bus (USB) dosimeter to track their own dose and feed it to a central database.	EQUIPMENT	Portable air sampler.	Personal air sampler.	Base stations with air samplers.	Wind-sock filters or items such as tacky shades.	Buildings air filters.	Vehicle air filters.	Industry air monitors.
		DESCRIPTION	Monitors airborne radioactive particles through calibrated air sampling onto filter media. 	Highly portable sampler for airborne radioactive particles. 	Fixed, near-real-time air filter stations city- and nation-wide to monitor airborne radioactive particles. 	Designed to capture airborne particles for subsequent analysis. 	Residential and industrial air filters capture airborne radioactive particles. 	Vehicle air filters can capture radioactive particles. 	Indoor and outdoor air monitors. 
		ADVANTAGES	In-line monitoring of beta/alpha in some models.	In-line monitoring of beta/alpha in some models, highly portable.	Existing GIS integration, rugged.	Improved version used at Sellafield charges the sock for electrostatic attraction to dust. Low cost.	Universal use in buildings and residences with filters, regular maintenance and replacement schedules.	Plenty of municipal, commercial vehicles available, regular maintenance and replacement schedules.	Nuclear industry standard.
		LIMITATIONS	Limited quantity available, not rugged, no GIS integration. Filter analysis is time-consuming.	Limited quantity available, ruggedness, no GIS integration. Filter analysis is time-consuming.	Limited quantity available, fixed locations.	No GIS integration, filter analysis.	No GIS integration, unknown performance on radioactive particles, filter analysis.	No GIS integration, little known performance on radioactive particles, filter analysis.	Limited quantity available, cost, filter analysis.
		R&D NEEDS	Guidance on use (LR). Rugged packaging (LR, BE). GIS integration (LR, BE, PE).	Guidance on use (LR). Rugged packaging (LR, BE). GIS integration (LR, BE, PE).	Survey of inventory (LR)	Survey of inventory (LR). GIS integration tools (LR, BE, PE). Guidance on use (LR).	Filter efficiency (BE). GIS integration tools (LR, BE, PE).	Filter efficiency (BE). GIS integration tools (LR, BE, PE).	Survey of inventory (LR). Guidance on use (LR).

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TABLE 3-1-4 Support Goal: Survey and Monitoring for Scenario 4

Scenario Description	Summary	Category	Column Number						
			1	2	3	4	5	6	7
Scenario 4: **Track contamination from the initial deposit area to other areas via vehicle and personnel transport.** What equipment and methods can be used to identify these contaminated egress routes? For instance, can vehicles originating from a contaminated zone be tracked using existing highway cameras?	• Much, if not all, of the discussion on general surveying from scenarios 1-3 applies here. • Monitoring and decontaminating, where appropriate, of vehicles exiting the contaminated areas would be required. To monitor vehicles, filters from vehicle heating, ventilation, and air conditioning (HVAC) systems can be pulled. In addition, sanitation trucks currently pass through portal monitors before entering waste transfer stations. • To monitor and control contamination on private vehicles, portal monitors or portable speed bump systems at strategic locations (tunnel/bridge entrances, expressway ramps, tollways) can be used. Contaminated cars can be diverted through vehicle wash units (or ad hoc systems) used for garbage trucks and buses. • Could also drive vehicles over tacky mats to remove contamination from tires. Mats can be monitored to show trends and areas most affected. • A massive distribution of handheld dosimetry devices around cities, neighborhoods, and subdivisions could be used. Real-time data output could be directed to stakeholders (e.g., homeowner association websites) to maintain awareness and transparency (public trust). • Concerns would include maintaining QA/QC of data originating from untrained users and integrating GIS into equipment used for detection or tracking.	EQUIPMENT	Tacky mats for vehicles.	Airborne wide-area monitoring.	Mobile phone with location tracking	Automatic plate number recognition (tollways).	Portable monitors on tracked vehicles.	Vehicle air filters.	Radiation speed bump detectors.
		DESCRIPTION	Controls loose contamination and can be adapted to remove rad particles from tires. 	Detector systems on helicopter or unmanned aerial vehicle can map contamination quickly. 	Can track people in contaminated area. 	Can track suspected contaminated vehicles for follow-up (long-term) assessment. 	Monitors added to select vehicles can provide quality data to assess contamination on routes. 	Vehicle air filters can capture radioactive particles. 	Real-time detection to segregate contaminated vehicles. 
		ADVANTAGES	Different sizes and colors, low cost, large numbers COTS.	Proven asset for immediate and prolonged survey (e.g., Airborne Radiological Enhanced-sensor System program under DHS).	Existing network of phones, mobile.	Local use, proven system.	Select vehicles for best coverage, better QA/QC control.	Plenty of municipal commercial vehicles available, undergoing regular maintenance.	Mobile.
		LIMITATIONS	Handling and disposal, manpower for change-out, small footprint compared to vehicles.	Low resolution, gamma radiation only.	Data access, privacy concerns.	How to link plate information to suspected contamination? Radiation monitor is not integrated.	Vehicle selection, trained operators, GIS tracking, gamma and possibly beta only.	No GIS integration, little known performance on radioactive particles, filter analysis.	Only one supplier, gamma only.
		R&D NEEDS	Practicality for outdoor vehicle use (LR). Removal efficiency (BE, PE).	Understand latest capabilities (LR). Rad detection integration (PE).	Practicality given privacy concerns (LR).	Rad detection integration and practicality (LR, PE).	Guidance to determine best vehicles (LR). GIS integration tools (LR, PE).	Filter efficiency (BE). GIS integration tools (LR, BE, PE).	Survey of inventory (LR). Guidance on use (LR, BE, PE).

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TABLE 3-1-5 Support Goal: Survey and Monitoring for Scenario 5

Scenario Description	Summary	Category	Column Number			
			1	2	3	4
Scenario 5: How would the above equipment and methods differ if **the contamination occurred at critical infrastructure** such as a hospital, wastewater reclamation facility, drinking water treatment plant, airport, or communication?	• Much, if not all, of the discussion on general surveying from scenarios 1-4 applies here. • Hospitals and other critical facilities would require immediate surveys and gross decontamination to mitigate doses followed by either decontamination or fixing of contamination in place pending future cleanup. This would allow critical facilities to continue to operate until the incident had been stabilized. • Drinking water treatment plants would probably be taken offline until full monitoring and remediation was complete. These would be priority facilities. They may require immediate access to portable filtration/ion exchange plants as part of the remediation. • The predicted effect on critical infrastructure needs to be assessed. Guidance on equipment use specific to critical infrastructure and GIS integration will be necessary.	EQUIPMENT	Portal monitors.	Manned, detailed measurement surveys.	Radiation speed bump detectors.	Industry air monitors.
		DESCRIPTION	Can be used to segregate contaminated vehicles at strategic locations. 	Portable instruments for trained operators. 	Real-time detection to segregate contaminated vehicles. 	Common nuclear industry and laboratory equipment for continuous monitoring. Direct or indirect analysis of air or filters. 
		ADVANTAGES	In use throughout country to detect radioactive material or contamination. Many designs available for cars, trucks, and rail cars.	Large numbers COTS, mobile.	Mobile.	Nuclear industry standard.
		LIMITATIONS	Limited COTS.	No GIS integration, significant manpower, background radiation interference.	Limited number of suppliers, gamma only.	Cost, filter analysis.
		R&D NEEDS	Survey of inventory (LR).	Guidance on use specific to critical infrastructure (LR). GIS integration tools (LR, BE, PE).	Guidance on use specific to critical infrastructure (LR). GIS integration tools (LR, BE, PE).	Guidance on use specific to critical infrastructure (LR). GIS integration tools (LR, BE, PE).

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TABLE 3-1-6 Support Goal: Survey and Monitoring for Scenario 6

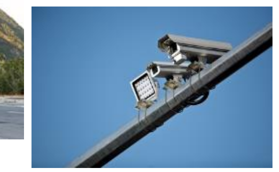
Scenario Description	Summary	Category	Column Number				
			1	2	3	4	5
Scenario 6: **Other ideas related to monitoring and procedures**: a. Can traffic cameras be used to evaluate the most traveled thoroughfares? b. Can traffic cameras or red-light cameras be used to track the most severely contaminated individual vehicles for follow-up survey? c. Can resulting dose maps be used to determine the best evacuation route to reduce the amount of exposure and facilitate the tracking of radioactive contamination?	a. Technology for monitoring traffic flow in major cities is mature technology. Traffic cameras are used extensively on motorways. Google traffic (and equivalents) may be more effective at analyzing general vehicle data. b. In principle, it would be possible to link plate recognition cameras to radiation sensors so contaminated vehicles can be detected. It may be easier to track vehicle owners rather than vehicles themselves because traffic cameras do not cover all roads. Voter registration data for residential areas or attendance lists for businesses may provide good coverage for people in a particular area. These individuals could be contacted for follow-up monitoring at their home addresses. c. Presume this could be done. Dose may be different from contamination (i.e., high-dose areas may not correspond to areas where contamination is most mobile). However, it is likely that dose maps would not be generated quickly enough to influence evacuation. Evacuation routes are already planned based on wind direction data on some nuclear sites, so the same principle could be extended to dose rate data gathered by first responders. Known safe routes could be reinforced during the recovery phase and combined with site security to ensure secure work areas.	EQUIPMENT	Traffic trackers.	Automatic plate number recognition (tollways).	Dose mapping to inform evacuation.	Portal monitors at strategic intersections.	Rad cams tied into traffic cam network.
		DESCRIPTION	Monitor traffic patterns to identify potentially contaminated routes. 	Can track suspected contaminated vehicles for follow-up (long-term) assessment. 	Create dose maps of thoroughfares to direct preferred evacuation routes. 	Can be used to segregate contaminated vehicles at strategic locations. 	Rad cams would flag a contaminated vehicle and the traffic camera would identify the plate for follow up. 
		ADVANTAGES	Mature technology in use.	Local use, proven system.	May limit the number of contaminated routes.	In use throughout country to detect radioactive material or contamination. Many designs available for cars, trucks, and rail cars.	Could provide contaminated vehicle discrimination.
		LIMITATIONS	None identified.	How to link plate information to suspected contamination? Radiation monitor is not integrated.	Dose maps would not be generated quickly enough to influence evacuation.	Limited COTS.	Not a current capability.
		R&D NEEDS	Research technology for monitoring traffic flow (LR), guidance on use (LR).	Practicality and whether linking is possible (LR).	Data from Fukushima experience (LR).	Survey of inventory (LR).	Research capability of rad cams (LR). Use in combination with traffic cams (PE).

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TABLE 3-1-7 Support Goal: Survey and Monitoring for Scenario 7

Scenario 7	Responses							
Question to participants: Do you have other thoughts or specific questions related to this topic based on your experiences in your geographical area?	The most experienced existing monitoring personnel would be best deployed on: • High-hazard/high-value activities (e.g., evidence recovery), • Containment activities to prevent the situation from degrading further (e.g., contamination monitoring at defined boundaries between areas), • Training additional resources to provide operational monitoring within the remediation zones), and • Clearance monitoring for priority areas that need to return to operation quickly. It would be beneficial to establish some monitoring stations where less-trained staff can use automated monitoring (such as hand and foot monitors) with little risk. These types of stations already exist at Chernobyl.	There appear to be several companies that produce systems for wide-area monitoring. However, it is generally not believed that these would satisfy all requirements, specifically: • Measurement of beta radiation, • Common data formats, • Wireless remote upload of data. Therefore, there may be systems available, but running their own custom-made software, databases, etc. Difficult/ time-consuming to import all data types into one GIS database. If authorities had a standard GIS system setup for such emergencies, then a standard data format could be published to the supply chain. This would significantly increase capability.	Data mapping systems require significant effort to set up and manage, especially if the area includes large numbers of complex structures. The “heat” of an incident is not the best time to determine the requirements for a data logging and visualization system. This should be considered a task that could be, in part, completed prior to any incident.	Data recording within buildings could, in theory, be performed by installed monitors that report readings automatically. For larger buildings and businesses that have air conditioning, the air inlets/filters could be monitored. Such data recording systems are used within nuclear plants throughout the world.	In practice, there would not be enough time, money, or systems available to set up such a comprehensive system. In the short to medium term, the easiest system to set up would be to provide residences (or groups of residence) monitoring equipment and ask for readings to be supplied regularly. The training is minimal and is only reliant on enough suitable pieces of equipment being available. There is a wide variety of equipment available from the supply, which all provide gamma dose rate.	Air samplers Question: is/are there enough: • Suitable systems available? • Personnel to install and maintain them? • Money available? • Need/desire to do this?	Guidance on use and GIS integration of the equipment listed will be necessary.	A few things that must be kept in mind are that: 1) Different detectors serve different purposes and have different capabilities. For instance, some are GPS-enabled; some detectors saturate at relatively low levels of contamination; detectors provide different outputs as some are dose meters, spectrometers, or exposure meters; and some detectors transmit data automatically, but the vast majority do not. 2). The goal of the mapping must be explained. Is it to provide information to the public or to characterize a surface for decontamination?

TABLE 3-1-8 Support Goal Training: Survey and Monitoring for Scenarios 1-7

Support Goal Training: Scenarios 1-7	Summary	Responses							
Question to participants: What are your thoughts and recommendations on **availability of trained human assets and training of additional assets** that will likely be needed in order to accomplish the scenarios under this goal? It is understood that training will be a significant effort and an additional limiting factor in any response scenario. Further, it may need to be addressed more thoroughly in the future, but input is needed to help guide how training guidance should be developed.	• Wide-area radiological contamination incidents are rare, and a response to such an incident will require tremendous human assets. Lessons learned from the cleanup efforts in Japan show that many thousands of individuals each day are engaged in cleanup activities. • For smaller incidents, all surveying and monitoring work would be completed by trained health physicist (HP) monitors with radiation instrumentation. During a larger incident, there may be a requirement to ask members of the public to perform basic surveying, potentially using smart-phone capabilities.	There is a limited number of suitably qualified and experienced persons (SQEPs) and companies that offer proper training. Sections of a typical national vocational qualification (NVQ) syllabus could be extracted to meet the requirements of different roles. A general approach to grade the level of training required could be considered, such as those listed in the next cells.	Level 1: Low-risk activities (e.g., operating a monitoring vehicle while remaining in a sealed cab at all times). Personnel would have a basic understanding of radiological risk and understand the dress, undress, and monitoring procedures for their role.	Level 2: Low-risk activities such as monitoring items and personnel moving between relatively clean areas (such as from sealed vehicle cabs at designated clean areas).	Level 3: These would be people with baseline training as noted in Levels 1 and 2, and some experience, who have demonstrated competence in their technical field.	Level 4: These would be people who have more experience and a broader knowledge of the operations and required controls.	Level 5: These are fully competent and experienced personnel who could lead and mentor lower-level personnel.	Provision of basic radiation awareness training can be web- (e-learning) or classroom-based learning. There will be a requirement for practical sessions and supervision for all persons who are new to radiological hazards.	Persons who have a basic understanding of radiation and contamination (nuclear facilities, non-nuclear facilities, hospitals, emergency services, and some military personnel), or have an understanding of other hazards (asbestos or chemicals) that can be applied to radiation/contamination hazard.

3.2 SUPPORT GOAL: MITIGATION OF RECEIVED DOSE TO FIRST RESPONDERS

Radiation dose burden for response personnel is a concern and must be reduced. What types of municipal and commercial equipment can carry out gross decontamination of contaminated surfaces and can contain and prevent the resuspension and tracking of contamination—either through the effects of wind or vehicle transport—during the mitigation phase of the response to reduce the dose burden to first-responder teams? Examples include using fireboats from a Port Authority to knock down radioactivity levels near the shore or dump trucks and bobcats to spread mulch and gravel across roadways to reduce the spread of contamination during vehicle transport. Note that “gross decontamination” is a type of decontamination whose goal is to reduce contamination levels. This reduction may not reach final cleanup levels, but it may be useful to mitigate some public hazard or contain contamination. Tables 3-2-1 to 3-2-10 present various scenarios related to mitigation of the received dose to first responders, possible responses to the scenarios, and possible equipment/technology used in responding, including its advantages, limitations, and R&D needs.

TABLE 3-2-1 Support Goal: Mitigation of Received Dose to First Responders for Scenario 1

Scenario Description	Summary	Category	Column Number					
			1	2	3	4	5	6
Scenario 1: Airborne contamination is a significant source of radiation dose to unprotected people. Given that contamination after settling is primarily found on horizontal surfaces (e.g., streets, walkways, parking lots, urban green spaces), reducing the potential for resuspension is potentially important. Prior research identified **materials such as gravel, mulch, and sand as effective means of reducing resuspension if the material can be laid down over the contaminated surface.** How would such material be distributed over an area of several linear blocks? How would such material be distributed over an area of several square miles?	• All methods that add material (e.g., gravel, mulch, sand) may increase the volume of radioactive waste. • Several kinds of equipment identified will be impractical in terms of distributing or spreading the quantity needed. Dump trucks can handle large capacities, but will require additional equipment to spread the material. Information gathering will be necessary to determine whether the listed equipment is capable of distributing or spreading materials such as gravel, mulch, and sand. • A common unresolved issue is that mechanical equipment used for this work is not typically supplied with sealed cabs and HEPA filtration. Therefore, operator PPE needs to be addressed and equipment may need to be modified prior to use.	EQUIPMENT	Small drop spreader.	Medium salt spreader.	Large salt spreader.	Large chip spreader.	Dumper truck.	Track-type tractor.
		DESCRIPTION	Used to spread small particles (fertilizer, sand, seed, salt) on small areas. 	Used to spread small to medium particles (sand, salt, gravel) on roadways and parking lots. 	Used to spread small to medium particles (sand, salt, gravel) on roadways and parking lots. 	Used to spread small to large gravel to repave roadways and parking lots. 	Capable of dumping all types of materials. 	Used to spread mulch and potentially other materials. 
		ADVANTAGES	Able to treat small or poorly accessible areas. Large number COTS.	Attached to pickup truck. Large numbers COTS in cold climates.	Fully automated with wet/dry combination spraying/spreading. Large numbers COTS in cold climates.	Large rate of coverage, fully automated with conveyors to spread aggregate.	All sizes available, large quantities available, large capacity, COTS.	COTS, availability. Could be used with a dumper truck.
		LIMITATIONS	The coverage rate of material may not be sufficient for the goal.	The rate of coverage/ dispersion rate may not be sufficient for the goal.	Rate of coverage/ dispersion may not be sufficient for the goal.	Availability.	Gross spreader. Dumps. Does not spread.	Coverage is limited. Large quantities may be needed.
		R&D NEEDS	Dispersion rate (LR).	Compatibility with material other than salt (LR). Dispersion rate (LR).	Compatibility with material other than salt (LR). Dispersion rate (LR).	Survey of inventory (local, regional, national, private, commercial) (LR). Best practice guidance (LR).	Effective ways to spread dumped material (LR).	Survey of inventory (LR).

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TABLE 3-2-2 Support Goal: Mitigation of Received Dose to First Responders for Scenario 2

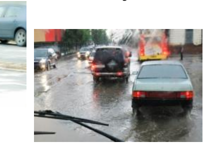
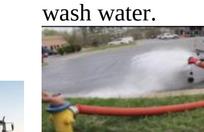
Scenario Description	Summary	Category	Column Number 1	2	3	4	5	6	7	8	9	10	11	12	13
Scenario 2: Airborne contamination is a significant source of radiation dose to unprotected people. Given that the contamination after settling is primarily found on horizontal surfaces (e.g., streets, walkways, parking lots, urban green spaces), reducing the potential for resuspension is potentially important. Prior research and experience identified that **washing surfaces with fresh water effectively removes contaminated particles, thereby reducing the dose in the immediate area**. How would fresh water be distributed over an area of several linear blocks? How would fresh water be distributed over an area of several square miles? How do methods change if water needs to be distributed over vertical surfaces such as building facades?	• Water may not be effective at removing particulates, but it could remove or suppress particulates that could aerosolize. This is not ideal, but it may be sufficient to reopen a road and reduce resuspension. Common supply sources include fire hydrants or local waterways. It is important to remember that misting surfaces to reduce resuspension may not be an option in dry or hot climates. This method of remediation may necessitate greater protection for buildings; particular care should be given to preventing water from getting into the buildings. • Guidance is needed to instruct workers on manner of use (flow rates, pressure, coverage rate, water collection, storage). • We need to work with wastewater and storm management locals to determine the best ways to contain and treat. • Many of these items are not readily available, and the coverage/ dispersion rate may be insufficient for the goal. More information will be necessary to determine equipment availability and water dispersion rates. • There will be policy and liability issues with the procurement of private equipment. • Mechanical equipment used for this work does not typically have sealed cabs or HEPA filtration.	EQUIPMENT	Portable water trailers.	High-capacity water pump.	Small-area misting/ Fogging.	Medium-area fogging/misting.	Commercial large-area misting/ Fogging.	Existing hoses (e.g., firefighting hoses) and personnel.	Firefighting aircraft dumpers.	Bambi bucket.	Agricultural aircraft.	Road sweepers.	Natural precipitation.	Agricultural sprayers.	Fire hydrant diffusers.
		DESCRIPTION	50–500-gallon capacity. 	Can move enormous volumes. 	Designed to provide aerosol of water to cool or dampen to reduce dust. 	Designed to provide aerosol of water to cool or dampen to reduce dust. 	Designed to provide aerosol of water to cool or dampen a surface to reduce resuspension hazards. 	Provides rapid cover of surfaces with variable fan pattern and volume. 	Designed to fight fires by deluging an area with water from a nearby water source. 	Designed to fight fires by deluging an area with water from a nearby water source. 	Crop dusters or top spreaders spread pesticides or fertilizers over large tracts. They can similarly spread water-based solutions. 	Provides mist of water to control dust. 	Rain or snow frequency varies regionally and seasonally. 	Designed to spread pesticide, herbicide, or fertilizer over fields. They can similarly spread water-based solutions. 	Firehose connected to water supply can be connected to a mobile diffuser mounted on truck to better direct wash water.  
		ADVANTAGES	Large capacity, portable.	Huge capacity. Pumps up to 20,000 liters per minute.	Flexible design, COTS.	Flexible design, COTS.	Large coverage area, flexible design.	Large quantities available, COTS. Large volumes if there is access to water supply such as a hydrant.	Can treat large areas, large volumes (800-20,000 gallons).	Large volume capacity (up to 2,600 gallons).	Large coverage rate, versatile aircraft.	Large quantities available, COTS, large coverage rates. Suppresses dust. Collects water.	Large coverage rate, inhabited and uninhabited areas.	Large coverage rate.	COTS allows for more versatile distribution of water for various water wash down needs (e.g., pavement, vehicles).
		LIMITATIONS	Availability. Coverage or dispersion rate of material may not be sufficient for the goal.	Availability.	Coverage or dispersion rate of material may not be sufficient for the goal.	Coverage or dispersion rate of material may not be sufficient for the goal.	Availability. Coverage or dispersion rate of material may not be sufficient for the goal.	Guidance for use requires trained personnel.	Gross spreader, availability. Requires trained personnel. The impact of water dropped at elevation can damage structures.	Gross spreader, availability. Requires trained personnel. The impact of water dropped at elevation can damage structures.	Amount of material may be insufficient for the goal.	Amount of material may be insufficient for goal. Exhaust could spread contamination.	Unpredictable frequency and volume. Collection and containment may be difficult.	Amount of material may be insufficient for goal. Coverage or dispersion rate of material may not be sufficient for the goal.	None identified.
		R&D NEEDS	Survey of inventory (LR).	Survey of inventory (LR).	Survey of inventory (LR). Practicality for large area (LR).	Survey of inventory (LR). Practicality for large area (LR).	Survey of inventory (LR). Practicality for large area (LR).	Best practice guidance (LR).	Survey of inventory (LR). Guidance on use (LR, BE, PE).	Guidance on use (LR, BE, PE). Survey of inventory (LR).	Survey of inventory (LR). Guidance on use (LR, BE, PE). Practicality for large area (LR).	Guidance on use (LR, BE, PE). Methods to control dust and emissions (LR).	Storm water containment technologies (LR).	Survey of inventory (LR). Practicality for large area (LR).	Guidance on use (PE).

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TABLE 3-2-3 Support Goal: Mitigation of Received Dose to First Responders for Scenario 3

Scenario Description	Summary	Category	Column Number 1	2	3	4	5	6	7	8	9	10	11	12	13
Scenario 3: Airborne contamination is a significant source of radiation dose to unprotected people. Because contamination after settling is primarily found on horizontal surfaces (e.g., streets, walkways, parking lots, urban green spaces), reducing the potential for resuspension is potentially important. Based on prior research and experience, it is known that washing surfaces with water containing salt (e.g., seawater or salty water from water softener units) effectively removes contaminated particles and fixed contamination from surfaces, reducing the dose in the immediate area. **How would the salt water be generated and distributed** over an area of several square blocks? How would it be distributed over an area of several square miles? How do the methods change if the salt water needs to be distributed over vertical surfaces such as the facades of buildings?	• EPA studies have shown that salt is not good for shielding radiation, but it is a good suppressant and will reduce resuspension. • Salt could be spread in a solid form, and rain allowed to mix with it to make a solution. It was agreed that a salt-water solution is more effective than rain alone. If spreading a solution, a cost analyses would need to be done to compare seawater vs. onsite mixing. Participants referenced a study that showed dry salts to have no effect on fertility of soil. However, when a saline solution was applied, it killed the vegetation and caused more dust to aerosolize from barren soil. • As in Scenario 2, pumps and misting equipment can be used with seawater/salty water, although corrosion may affect long-term lifespan. • The same concerns over proper use, coverage rates, water containment, worker protection apply.	EQUIPMENT	Intermediate bulk container (IBC) tote mixer.	IBC pump and sprayer.	Existing hoses (e.g., firefighting hoses) and personnel.	Firefighting aircraft dumpers.	Bambi bucket.	Agricultural aircraft.	Portable water trailers.	High capacity water pump.	Small area misting/ fogging.	Medium area fogging/ Misting.	Commercial large area misting/ Fogging.	Road sweepers.	Stockpiled rock salt for deicing.
		DESCRIPTION	Diverse category of industrial mixers designed to meet various needs for agitation in these containers. 	Pumps are designed to move liquids from these portable, stackable containers. https://www.asphaltsealcoatingdirect.com/products/asd275-portable-sealcoating-spray-system	Provide rapid cover of surfaces with variable fan pattern and volume. 	Designed to fight fires by deluging area with water from nearby water source. 	Designed to fight fires by deluging an area with water from a nearby water source. 	Crop dusters or top spreaders spread pesticides or fertilizers over large tracts. They can similarly spread water-based solutions. 	50–500-gallon capacity. 	Can pump water at rates of up to 1000 m^3/h. 	Designed to provide aerosol of water to cool or dampen to reduce dust. 	Designed to provide aerosol of water to cool or dampen to reduce dust. 	Designed to provide aerosol of water to cool or dampen to reduce dust. 	Provides mist of water to control dust. 	Sodium-based deicing salt can be used to create effective wash solution to improve de-contamination. 
		ADVANTAGES	Up to 250-gallon capacity, large quantities available COTS.	Hand or electric pump, large quantities available COTS.	Large quantities available COTS.	Can treat large areas, large volumes (800-20,000 gallons).	Large volume capacity (up to 2,600 gallons).	Large coverage rates.	Large capacity, portable.	Huge capacity.	Flexible design, COTS.	Flexible design, COTS.	Large coverage area, flexible design.	Large coverage rates. Suppresses dust. Collects water.	Common in northern U.S. cities, large stockpiles, existing supply chain.
		LIMITATIONS	None identified.	None identified.	Salt supply needs to be integrated into spray system. Incompatible with salt.	Gross spreader, limited availability. Requires trained personnel. The impact of water dropped at elevation can damage structures.	Gross spreader, availability. Requires trained personnel. The impact of water dropped at elevation can damage structures.	Amount of material may be insufficient for goal. Incompatibility with salt.	Availability, incompatible with salt. Coverage or dispersion rate of material may not be sufficient for the goal.	Availability, incompatible with salt.	Coverage or dispersion rate of material may not be sufficient for the goal. Incompatible with salt.	Coverage or dispersion rate of material may not be sufficient for the goal. Incompatible with salt.	Availability, incompatible with salt. Coverage or dispersion rate of material may not be sufficient for the goal.	Amount of material may be insufficient for goal. Exhaust could spread contamination. Incompatible with salt.	Product variety, uncommon in southern states.
		R&D NEEDS	None identified.	None identified.	Guidance on effect of different salts and concentrations (LR, BE, PE). Compatibility with salt (LR).	Survey of inventory (LR). Guidance on use (LR, BE, PE).	Survey of inventory (LR). Guidance on use (LR, BE, PE).	Survey of inventory (LR). Compatibility with salt (LR).	Survey of inventory (LR). Compatibility with salt (LR).	Survey of inventory (LR). Compatibility with salt (LR).	Survey of inventory (LR). Compatibility with salt (LR). Practicality for large area (LR).	Survey of inventory (LR). Compatibility with salt (LR). Practicality for large area (LR).	Survey of inventory (LR). Compatibility with salt (LR). Practicality for large area (LR).	Guidance on use (LR, BE, PE). Compatibility with salt (LR). Methods to control dust and emissions (LR).	Research salt varieties recommended for use (LR).

TABLE 3-2-3 (Cont.)

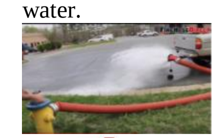
Scenario Description	Summary	Category	Column Number					
			14	15	16	17	18	19
		EQUIPMENT	Agricultural sprayers.	Small drop spreader.	Medium salt spreader.	Large salt spreader.	Paver trucks.	Fire hydrant diffusers.
		DESCRIPTION	Designed for distributing pesticide, herbicide, or fertilizer on fields. They can similarly spread water-based solutions. 	Used to spread small particles (fertilizer, sand, seed, salt) over small areas. 	Used to spread small to medium particles (sand, salt, gravel) on roadways and parking lots. 	Used to spread small to medium particles (sand, salt, gravel) on roadways and parking lots. 	Covers single lane of roadway in one pass with variable depth of asphalt. 	Firehose connected to salt water supply can be connected to a mobile diffuser mounted on truck to better direct wash water.  
		ADVANTAGES	Large coverage rate.	Can treat small or poorly accessible areas. Large number COTS.	Attached to pickups. Large number COTS in cold climates.	Fully automated with wet/dry combination spraying/ spreading. Large number COTS in cold climates.	Large quantities available COTS.	COTS allows for more versatile distribution of water for various water wash down needs (e.g., pavement, vehicles).
		LIMITATIONS	Coverage or dispersion rate of material may be insufficient for the goal. Compatibility with salt.	Coverage or dispersion rate of material may not be sufficient for the goal.	Rate of coverage/ dispersion may be insufficient for goal.	Rate of coverage/ dispersion may be insufficient for goal.	Incompatible with salt.	None identified.
		R&D NEEDS	Survey of inventory (LR). Compatibility with salt (LR). Practicality for large area (LR). Guidance on use (LR, BE, PE).	None identified.	Dispersion rate (LR). Guidance on use (LR, BE, PE).	Dispersion rate (LR). Guidance on use (LR, BE, PE).	Compatibility with salt (LR).	Guidance on use (PE).

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TABLE 3-2-4 Support Goal: Mitigation of Received Dose to First Responders for Scenario 4

Scenario Description	Summary	Category	Column Number						
			1	2	3	4	5	6	7
Scenario 4: How would the proposed methods of addressing Scenarios 1–3 change if the **contaminated area was located close enough to the ocean coastline or another navigable waterway** for maritime equipment and methods to be used?	• Waterborne equipment could draw water from the waterway and provide floating emergency accommodations. • Fireboats charge water lines to clean bridges with river and/or seawater. They could potentially decontaminate bridges and cars. • Standard personal, municipal, or commercial watercraft can also be used if pumps and hoses are added to the craft. The easy addition of pumps to normal craft would allow them to draw water directly from the ocean or waterway and pump it straight onto buildings. • Many of the items listed are not readily available or are limited to immediate coastal coverage. • There will be policy and liability issues with the procurement of private boats. Equipment is not designed for contaminated environments, and operator PPE needs to be addressed (estimate of the dose to workers is not established, estimated, or summarized).	EQUIPMENT	High-capacity water pump.	Fireboats.	Personal, municipal, and commercial watercraft.	Cruise/cargo ship.	Sand.	Fireboats and bridge decontamination.	Fire hydrant diffusers.
		DESCRIPTION	Can move enormous volumes of water. 	Designed for structures in or adjacent to waterway, but can supply water throughout city via piping. 	Personal, municipal, or commercial watercraft can be used if pumps and hoses are added to the craft. 	Accommodation for workers. 	Can cover contaminated fallout. 	Can decontaminate bridges and vehicles/equipment as they pass through. 	Firehose connected to salt water supply can be connected to a mobile diffuser mounted on truck to better direct wash water.  
		ADVANTAGES	Huge capacity. Pumps up to 20,000 liters per minute.	Pumps 2,000–50,000 liters per minute. Unlimited water supply, regional use.	Existing supply of watercraft.	Portable city to accommodate workforce.	Large volumes in areas with beaches.	Capacity.	COTS allows for more versatile distribution of water for various water wash down needs (e.g., pavement, vehicles).
		LIMITATIONS	Availability.	Water containment. For immediate coastal only. Use as continuous pump for seawater.	Available certified operators, available water pumps, DIY guidance, retrofitability, liability concerns. Limited to immediate coastal coverage.	Availability, decontamination.	Region specific.	Difficult to capture and contain contaminated water.	None identified.
		R&D NEEDS	Survey of inventory (LR). Compatibility with salt (LR).	Survey of inventory (LR). Best practice guidance (LR)	Liability concerns lessons from previous disasters (e.g., Sandy and Harvey) (LR). Apps used to recruit volunteers (LR). Survey of inventory (LR). Best practice guidance (LR).	Survey of inventory (LR). Decontamination guidance (LR).	Research ways to transport large volumes of sand (LR).	Research ways to contain contaminated wastewater on bridge (LR).	Guidance on use (PE).

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TABLE 3-2-5 Support Goal: Mitigation of Received Dose to First Responders for Scenario 5

Scenario Description	Summary	Category	Column Number													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scenario 5: Airborne contamination is a significant source of radiation dose to unprotected people. Because contamination after settling is primarily found on horizontal surfaces (e.g., streets, walkways, parking lots, urban green spaces), reducing the potential for resuspension is potentially important. Through prior research and experience, it is known that applying a sprayable polymer coating (the consistency of wet paint; e.g., outdoor paints and epoxies such as those designed for roadways or other paved surfaces) to the surfaces effectively ties down contaminated particles. How **would polymer coating material be distributed over an area of several square blocks? How would it be distributed over an area of several square miles**? How do methods change if the **coating needs to be distributed over vertical surfaces** such as the facades of buildings?	• There are systems that can be mounted to trucks to spray aerosols (e.g., for mosquito control). The fire department has equipment that can spray foam onto surfaces, but it is not known if they can spray a polymer. • For much of the equipment listed, compatibility with polymer and the application of this coating (coverage rate and thickness) are unknowns. • Sprayer nozzle size and viscosity of the coating are interdependent and need to be tested to ensure that the sprayer nozzle or hose will not clog.	EQUIPMENT	Remote sprayer platform.	Handheld sprayer.	Medium-area sprayer.	Large-area sprayer.	Emulsion sprayer (liquid asphalt) distributors.	Conventional paint.	Highway paint.	Bambi buckets.	Pothole patch trucks.	Paver trucks.	Water tankers and hoses.	Firefighting aircraft dumpers.	Agricultural sprayers.	IBC pump/sprayer, truck mounted.
		DESCRIPTION	Sprayer mounted on remotely operated vehicles. See https://www.dndkm.org/News/ICMSprayerPlatform.aspx?name=Technology%20Demonstration%20of%20Strippable%20Coatings%20via%20remote%20sprayer%20platform#	Latex and oil-based applicators. 	Latex and oil-based applicators. 	Aqueous sprayer such as an industrial water truck 	Sprays asphalt and with chip spreader can be used to seal-in-place the contamination. 	Provides rapid cover of surfaces. 	Provides rapid cover of surfaces. 	Designed to fight fires by deluging an area with water from a nearby water source. 	Designed for rapid cover of small potholes. 	Covers single lane of roadway in one pass with variable depth of asphalt. 	Provides large supply of fluid for spraying on surfaces. 	Designed to fight fires by deluging an area with water from a nearby water source. 	Designed for distributing pesticide, herbicide, or fertilizer on fields. They can similarly spread water-based solutions. 	Versatile design mounted on available trucks.[a] 
		ADVANTAGES	Remote operation.	Large quantities available for small applications (<5-liter capacity). Minimal waste.	Large quantities available for small applications (~20-liter capacity). Minimal waste.	Large-area applicator (2,000-liter capacity).	Sprays liquid asphalt for complete coverage of roadways. May spray polymer coating.	Large quantities available COTS.	Available COTS. Designed for outdoor paved surfaces and resistant to vehicle traffic.	Large capacity (up to 2,600 gallons).	Manual or automated trucks, large quantities available COTS.	Large quantities available COTS.	Large quantities available COTS, variable capacity tanks.	Can treat large areas, large volumes (800-20,000 gallons).	Large coverage rate.	Versatile for existing trucks, large coverage rates, on-vehicle water supply.
		LIMITATIONS	Compatibility with polymer, availability. Scaled-up designs not known.	Small coverage rate.	Small coverage rate.	Compatibility with polymer, availability.	Compatibility with polymer, availability.	Ruggedness, coverage rate	Coverage rate and supply for gross coverage of paved areas.	Gross spreader, compatibility with polymer, availability. Requires trained personnel. The impact of water dropped at elevation can damage structures.	Coverage rate, compatibility with polymer.	Control over thickness to reduce rad waste upon removal.	Compatibility with polymer.	Gross spreader, availability, compatibility with polymer, ability to control layer thickness. Requires trained personnel. The impact of water dropped at elevation can damage structures.	Compatibly with polymer.	Compatibility with polymer.
		R&D NEEDS	Survey of inventory (LR). Compatibility with polymer (LR, BE, PE). Guidance on use (LR).	Guidance on use (LR).	Guidance on use (LR).	Survey of inventory (LR). Compatibility with polymer (LR and/or BE, PE). Guidance on use (LR).	Survey of inventory (LR). Compatibility with polymer (LR, BE, PE). Guidance on use with polymer or asphalt emulsions (LR).	Research effectiveness (LR, BE, PE).	Survey of inventory (LR).	Survey of inventory (LR). Compatibility with polymer (LR and/or BE, PE). Guidance on use (LR, BE, PE).	Guidance on use (LR). Compatibility with polymer (LR and/or BE, PE).	Compatibility with polymer (LR and/or BE, PE).	Compatibility with polymer (LR and/or BE, PE).	Survey of inventory (LR). Compatibility with polymer (LR). Guidance on use (LR, BE, PE).	Survey of inventory (LR). Compatibility with polymer (LR, BE, PE). Guidance on use (LR, BE, PE).	Survey of inventory (LR). Compatibility with polymer (LR, BE, PE).

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TABLE 3-2-6 Support Goal: Mitigation of Received Dose to First Responders for Scenario 6

Scenario Description	Summary	Category	Column Number						
			1	2	3	4	5	6	7
Scenario 6: How would the equipment and methods in Scenarios 1–3 (gravel, mulch, sand, fresh water, salt water) and 5 (sprayable polymer coating) differ if the **contamination occurred at critical infrastructure** such as a hospital, water reclamation facility, drinking water plant, airport, or communications center?	• Critical infrastructure (e.g., power plants, potable water treatment plants, sewer treatment plants, law enforcement facilities, hospitals) should be prioritized for immediate gross decontamination. They have heavy foot traffic and could easily uncover previously covered contamination. A short- or medium-term cleanup strategy would be necessary for these facilities to continue to operate until the incident stabilized. • Hospitals may be inherently easier to decontaminate because of their many hard surfaces. They also may already have protocols in place that could be implemented. • Gaps vary according to type of critical infrastructure and the requirements to prevent damage to sensitive equipment outside or within the facility. • Gaps will likely include effective ways to collect and contain wastewater and movement of airborne contamination. For drinking water, wastewater and stormwater collection systems, see McAfee[2] and Biwer.[3]	EQUIPMENT	Mobile wash units.	Specialized train rail and tunnel wash cars.	Jet engine blowers.	Vacuum trains.	Easier-to-clean surfaces.	Bridges.	Airport sprayer systems.
		DESCRIPTION	Supplies wash waters dispensed by manned-hose over small to medium areas. 	Spray jets clean the rail lines and scrub or wash tunnels.[a] 	Can remove debris from tracks with powerful airflow.[a] 	Trains designed to remove debris from rail lines.[b] 	Hospitals and other infrastructure with smooth, hard surfaces are more easily decontaminated. 	Can use existing standpipes or build ad hoc systems to spray fixatives or decontaminants onto vehicles (e.g., cars, trucks, rail stock, planes) and equipment (e.g., emergency response equipment, cargo containers).[c] 	Deicing equipment and aircraft washing capabilities can decontaminate surfaces. Military airbases often have built-in wash ramps on the runway. 
		ADVANTAGES	Mobile.	Specialized to infra-structure.	Powerful, large coverage rates, specialized to infrastructure.	Large coverage rate, specialized to infrastructure.	Current techniques for cleaning and washing may be sufficient.	Large coverage rate, specialized to infrastructure.	Specialized to infrastructure. Current techniques for cleaning and washing may be sufficient.
		LIMITATIONS	Local prevalence.	Water collection, effectiveness.	Limited numbers, uncontrolled movement of material.	Local prevalence, filtration efficiency.	Guidance specific to critical infra-structure.	Water collection, guidance specific to critical infra-structure.	Water collection, guidance specific to critical infrastructure.
		R&D NEEDS	Survey of inventory (LR).	Water collection/ containment methods (LR). Dose reduction assessment (LR, PE).	Survey of inventory (LR). Collection of material (LR, PE).	Filtration efficacy (LR). Survey of inventory (LR).	Best practice guidance from power plants, hospitals, etc. (LR).	Best practice guidance.	Best practice guidance.

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[2] McFee, J., Krishnan, R., Piao, H., & Randall, P. (2008). Decontamination Methods for Drinking Water Treatment and Distribution Systems. *Wiley Handbook of Science and Technology for Homeland Security*, 1-24.
[3] Biwer, B. M., Chen, S. Y., Monette, F. A., MacKinney, J., & Janke, R. (2008). Decontamination Methods for Wastewater and Stormwater Collection and Treatment Systems. *Wiley Handbook of Science and Technology for Homeland Security*, 1-26.

TABLE 3-2-7 Support Goal: Mitigation of Received Dose to First Responders for Scenario 7

Scenario Description	Summary	Category	Column Number					
			1	2	3	4	5	6
Scenario 7: Airborne contamination is a significant source of radiation dose to unprotected people. Because contamination after settling is primarily found on horizontal surfaces (e.g., streets, walkways, parking lots, urban green spaces), reducing the potential for resuspension is potentially important. Areas of concern would be covered in contaminated debris and loose particles. In some areas, the debris would be substantial and could be removed by bulldozer-type equipment. In other areas, the debris material could be swept and vacuumed. **How can contaminated debris be physically moved or removed?**	• In small areas, portable containment tents could be erected for dry cleanup work using HEPA vacuums, shovels, etc., and air handling systems with HEPA filters may be constructed. • Large inflatable tents could isolate and contain dust over large areas. Additional hazards must be assessed (e.g., wind). Portable containment tents may not be an option where heavy lifting equipment or tools are in use. • Airborne hazards could be controlled using misting technology, ranging from cheap misting hoses (for gardens) to industrial misting systems set up over larger areas. Misting suppresses airborne contamination, but wastewater containment would be necessary because contamination is more mobile when dissolved or suspended in liquid. • Street sweepers use both wet and dry technologies and would be suitable for use in damp environments. • Common concerns with the items used to remove debris (e.g., a street sweeper or HEPA vacuum) include removal efficiency based on particle characteristics, dust control, and worker protection.	EQUIPMENT	Portable decontamination tent.	Large tent.	Water spray or misting equipment (see Scenario 2 equipment).	Household-type HEPA vacuums.	Road sweepers.	Bulldozers, backhoes, front loaders, bobcats, etc.
		DESCRIPTION	Could contain small hotspots. 	Could isolate and contain dust over larger plots. 	Reduces dust generation from vehicle movement. 	Smaller area removal of dust and small debris plus HEPA filters. 	Provides mist of water to control dust. 	Moves debris into piles or into hauling vehicles. 
		ADVANTAGES	Custom and ad hoc systems available.	Large area containment.	See Scenario 2 equipment.	Nationwide distributors. Recent efficacy data is available.	Large quantities available COTS, large coverage rates. Suppresses dust. Collects water.	Large coverage rates, large quantities available for use.
		LIMITATIONS	Coverage rate.	Availability.	See Scenario 2 equipment. May not provide enough volume or force to physically move debris.	Effectiveness a function of particle characteristics, small coverage rate.	May be ineffective on small particles. Exhaust could spread contamination.	Hermetically sealed cabs not COTS.
		R&D NEEDS	None identified.	Survey of inventory (LR).	Survey of inventory (LR). Practicality (LR). Guidance on use (BE, PE)	Research removal efficiency (LR).	Research removal efficiency (LR and BE, PE). Guidance on use (LR, BE, PE). Methods to control dust and emissions (LR). Decontamination guidance (LR).	PPE needs to be addressed (LR). Cab design or retrofit for contaminated environments (LR and/or BE, PE). Dose to driver on routes (LR). Decontamination guidance (LR).

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TABLE 3-2-8 Support Goal: Mitigation of Received Dose to First Responders for Scenario 8

Scenario Description	Summary	Category	Column Number 1	2	3
Scenario 8: Regardless of scenario, how would the above equipment and methods differ if the **contamination occurred along egress routes** that are necessary to transport people away from the affected area (for example, major highways)?	• On key egress routes, gross decontamination would be deployed rather than coverings for dose mitigation or refined decontamination techniques. • Pressure washing would be a key way to remove as much primary contamination as possible and prevent resuspension of dry particulates from passing vehicles. • After pressure washing, paint or other durable surface coatings could fix residual contamination in place until egress or evacuation was complete and access more controlled. The whole surface could then be lifted for disposal if necessary. • Common issues include capturing and containing large amounts of contaminated water and finding effective coatings to cover contamination.	EQUIPMENT	Water wash-down activities.	Post-cleaning stabilization.	Fireboats and bridges.
		DESCRIPTION	Spraying water will only move activity to drainage near the roads. 	Following pressure washing, paint or other durable surface coatings can stabilize contamination. 	Use of fireboats can decontaminate bridges and passing cars. 
		ADVANTAGES	Availability.	Availability.	Capacity.
		LIMITATIONS	It is difficult to capture and contain large amounts of contaminated water.	Coating effective for radiation. Waste may be generated if coated material is disposed later.	It is difficult to capture and contain contaminated water.
		R&D NEEDS	Water collection and containment methods (LR). Dose reduction estimates (LR, PE).	Coating effectiveness (LR, BE, PE).	Contain contaminated wastewater on bridge (LR).

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TABLE 3-2-9 Support Goal: Mitigation of Received Dose to First Responders for Scenario 9

Scenario 9	Responses							
Question to participants: Do you have other thoughts or specific questions based on your experiences in your geographical area related to this topic?	Washing down surfaces or covering surfaces, with whatever agent, generates very significant amounts of secondary waste in the form of contaminated liquids and solids so tie-down coatings and paints are best option.	The use of salt addition requires very careful consideration. Surface water usually goes into rivers and streams after passing through water treatment works, but without any salt removal. Hence, there is a significant environmental detriment.	Sprayer nozzle size and viscosity of coating are interdependent and hence a high risk exists that improvised sprayers may become clogged. Therefore, any wide-area spraying devices need to be identified in advance for the materials to be used.	Not all polymer coatings are equal, and some may fragment rather than adhere strongly after application.	May need to consider that remediation personnel may be present in same area as public. Such staff are likely to be wearing PPE and possibly respiratory protective equipment that may not have been provided to the public in the same location. This may cause confusion and concern. Issuing everyone a dust mask and plastic gloves, as obtained from all DIY stores, will provide basic protection.	Any areas where waste accumulates may need to be shielded in advance or selected to minimize radiation to the general environment.	Under as low as reasonably achievable (ALARA) principles, early consideration needs to be given to waste transport or final disposal containers to reduce the dose associated with multiple repacking operations.	Rain frequency. The potential effects of rain frequency on mitigation will need to be understood and considered.

TABLE 3-2-10 Support Goal Training: Mitigation of Received Dose to First Responders for Scenarios 1-9

Support Goal Training: Scenarios 1-9	Summary	Responses				
Question to participants: What are your thoughts and recommendations on **availability of trained human assets and training of additional assets** that will likely be needed in order to accomplish the scenarios under this Goal? (It is understood that training will be a significant effort and an additional limiting factor in any response scenario. Further, it may need to be addressed more thoroughly in the future, but input is needed to help guide how training guidance should be developed.)	Wide-area radiological contamination incidents are rare, and a response to such an incident will require tremendous human assets. Lessons learned from the cleanup efforts in Japan show that many thousands of individuals each day are engaged in clean-up activities.	Contamination control and radiation safety training would need to be given to all personnel working within the remediation area to ensure that operations progress efficiently and dose to individuals is minimized. This will need to be regularly refreshed, and individuals will need to be supervised until they gain sufficient experience.	A common training program and procedure could be developed for rollout to the public and agencies to ensure a consistent approach by all parties and to reduce risk of confusion.	Local areas where remediation operations are underway are controlled to prevent public access as this would otherwise lead to increased risks and reduce the effectiveness of remediation work (e.g., due to cross-contamination risks).	Limited companies offer NVQ Levels 2/3 for Radiation Protection and Nuclear Decommissioning and a Level 2 for Process Industry Operations. Sections of a typical NVQ syllabus could be extracted to meet the requirements of different roles.	The general approach to grade the level of training required could be considered, as per the Survey & Monitoring Goal. If the contamination is truly at this real scale, then the first major resource is likely to come from the military, supported by fire and rescue services and civilian experts. Basic training in radiological protection can then be given to pertinent personnel. Their training will focus on operator safety.

3.3 SUPPORT GOAL: DECONTAMINATION (GROSS AND FINAL)

Decontamination methods can be more effective if implemented within days of a release rather than waiting months or years. Waiting can allow the contamination to evolve chemically and physically, rendering it more difficult to remove. What types of municipal and commercial equipment can carry out gross or final decontamination of contaminated surfaces? Examples include asphalt-milling machines to remove the top layer of road surfaces, bobcats to remove the top layer of vegetation or soil, and tillers to turn over contaminated soil. Note that “gross decontamination” is a type of decontamination conducted with the goal of reducing contamination levels. This reduction may not be sufficient for final cleanup levels, but it may be useful to mitigate some public hazard or to contain contamination. Tables 3-3-1 to 3-3-7 present various scenarios related to decontamination, possible responses to the scenarios, and possible equipment/technology used in responding, including its advantages, limitations, and R&D needs.

TABLE 3-3-1 Support Goal: Decontamination (gross and final) for Scenario 1

Scenario Description	Summary	Category	Column Number 1	2	3	4	5	6	7	8	9	10	11	12
Scenario 1: EPA studies identified that soil is a major source of contaminated material in decontamination efforts in an urban environment. Prior research and experience suggest that nearly all contamination can be removed by removing less than 5 cm (2 inches) of soil. This equipment would be useful in **removing a very shallow layer of soil, grass, or foliage from large urban green spaces such as playgrounds and open grass fields.**	• Common unresolved issues are: (1) Availability of privately-owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow their use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use. • A common shortcoming of shovel trucks is their inability to precisely control the depth of material removed. Experienced operators may be able to consistently remove 8 to 10 cm (3-4 inches). • Contaminated snow may need to be removed in its entirety if a method of removing just the top layer is not available. • Smaller excavators have better control. Larger excavators may give less control and more soil mixing but perform the work quicker. • Turf strippers remove sections from 30 cm to 2 m wide, dependent on size and flatness or openness of the area. Larger machines would require more specialist training. • Soil turnover provides additional shielding of radiation dose to public.	EQUIPMENT	Bobcats.	Small mechanical diggers.	Large excavators.	Turf stripper.	Vacuum trucks.	Bulldozer.	Conveyor segmented gate systems.	Crop duster or mobile spray for defoliation.	Soil stabilizer sprays.	Soil turnover, medium scale.	Soil turnover, larger scale.	Deep ploughing.
		DESCRIPTION	Small earthmover to clear debris or move contaminated solid waste. 	Small earthmover to clear debris, move contaminated solid waste, or dig a trench or hole. 	Large earthmover to clear debris, move contaminated solid waste, or dig a trench or hole. 	Removes a layer of grass for disposal. 	Can remove loose soil, gravel, dust, leaves, or small debris into on-board storage tank. 	Common construction equipment for pushing earth. Can be used to scrape top layer of earth for removal. 	Used to reduce the amount of solid waste by assaying 100% of soil or debris.[a] 	Can defoliate a wide or medium area of contaminated leaves for collection. 	Hardens top layer of soil to reduce dust and/or facilitate its removal as a hardened layer. 	Small plows attached to small or large vehicles can turn over the soil down to a depth of approximately 15 cm (6 inches) to bury radioactivity and shield against radiation. 	Tractor-towed plows (6 to 10 furrows) can turn over the soil up to 25 to 30 cm (10 to 12 inches) deep to bury radioactivity and shield against radiation. 	Largest plows pulled by specialty tractors can reach 50 cm (21 inches) in depth or more to bury radioactivity and shield against radiation.
		ADVANTAGES	Fast, efficient with a range of bucket sizes.	Combination excavator and grading plane useful for breaking up and removing layers.	Greater than 1-ton bucket, heavy lifting.	Large area turf stripper with controlled depth. Removing grass in early response can be very effective at removing contamination.	Better control than shovel trucks for removing loose debris.	Larger coverage with less-precise control than smaller shovel trucks.	Assay 100% of material, radionuclide discrimination, high throughput. Specifically developed and proven in radioactive soil applications.	Used in some cities. Large coverage rates.	COTS, large coverage rate, rugged.	Large quantities available COTS, good control for medium plots, DIY.	Large coverage rate, large quantities available COTS in rural areas.	Deep turnover provides highest dose reduction. Prior efficacy data available.
		LIMITATIONS	Depth control.	Depth control.	Depth control.	Removal rate.	Limited capacity (less than 5000 gallons), availability in numbers.	Depth control.	Cost-benefit, availability.	Availability, public acceptance. Requires trained personnel.	Little data on effectiveness.	Dust control, does not remove contamination, sufficient depth to reduce exposure.	Availability, dust control, sufficient depth to reduce exposure. Does not remove contamination.	Availability, dust control. Does not remove contamination.
		R&D NEEDS	Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR). Survey of inventory (LR). Clarify transport regulations (LR).	Best practice guidance (LR).	Cost benefit analysis compared to other options (LR). Availability (LR).	Survey of inventory (LR).	Data from Fukushima experience (LR). Efficacy for radionuclide removal (formulation, depth, and spray parameters) (LR, BE).	Exposure reduction estimates (LR). Expected uptake of radionuclides into grasses, plants, and trees (LR). Best practice guidance (LR).	Exposure reduction estimates (LR). Expected uptake of radionuclides into grasses, plants, and trees (LR). Survey of inventory (LR). Best practice guidance (LR).	Survey of inventory (LR). Best practice guidance (LR).

TABLE 3-3-1 (Cont.)

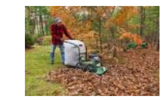
Scenario Description	Summary	Category	Column Number 13	14	15	16	17	18	19	20
		EQUIPMENT	Beach cleaning machines.	Snow plows.	Current city resources for fallen tree removal.	Booms.	Residential mowers.	Tractor mower.	Hedge cutters.	Lawn sweeper/ vacuum.
		DESCRIPTION	Equipment removes the top layer of sand and sifts it to remove large objects. May be adapted to remove sand layer. 	Can remove contaminated snow or be repurposed to move soil and vegetation. 	Available assets to lift, trim, cut, remove, mulch, and haul foliage and trees. 	Elevated lift to facilitate collection, washing of trees and buildings, etc. 	Lawn mowers of various size can cut and remove contaminated grass. 	Large mowers can cut and remove contaminated grass. 	Hand tools like hedge cutters and shears can remove contaminated foliage. 	Designed to remove leaves and mulch from short grass. 
		ADVANTAGES	Large coverage rate, specialty equipment. Efficacy data available.	Large quantities available COTS in colder climates, large coverage rate.	City resources, specialized and trained staff, variety of tasks.	Large quantities available COTS.	Large quantities available, DIY, collects clippings.	Existing network, regular operating schedule, trained operators, large coverage rate.	Large quantities available, DIY.	DIY, good coverage rate. Designed to handle leaves, twigs, and other small plant debris.
		LIMITATIONS	Availability, dust control. Requires modification (binder) to remove contaminated top layer.	Availability in warmer climates, depth control.	Dust control.	None identified.	Dust control, operator exposure, only removes contamination on grass blades.	Drops clippings. Dust control, operator exposure, only removes contamination on grass blades.	Collecting clippings.	May not be effective on grass clippings.
		R&D NEEDS	Binder materials to create separable surface layer (LRS, BE). Survey of inventory (LR).	Disposal plan options and guidance (LR).	Best practice guidance (LR).	None identified.	Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR).

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TABLE 3-3-2 Support Goal: Decontamination (gross and final) for Scenario 2

Scenario Description	Summary	Category	Column Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Scenario 2: Same as Scenario 1, except that the intent is to identify equipment that would be useful in **removing a very shallow layer of soil, grass, or foliage from smaller, discontinuous plots** of urban green spaces such as front and back yards and garden areas.	• Common unresolved issues are: (1) Availability of privately owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use. • Where specialist remediation support is not required, DIY options may be important. Shovels, hoses, spray washers, and wipes supplied to landowners are cost-effective methods of remediation. For DIY equipment, a best practices guidance is not available and would need to be published to reduce risk. • Power washers can remove contamination from hard surfaces like rock gardens, rock lawns, pavers, driveways, siding, and roofs. Guidance is needed regarding manner of use (flow rates, pressure, coverage rate, water collection and storage).	EQUIPMENT	Shovel.	Bobcats.	Small mechanical diggers.	Turf stripper.	Soil turnover, small scale.	Soil turnover, medium scale.	Vacuum trucks.	Hand wiping.	Pressure washing.	Brushing/ scrubbing.	Conveyor segmented gate systems.	Residential mowers.	Hedge cutters.	Lawn sweeper/ vacuum.
		DESCRIPTION	Manual removal of contamin-ated solids. 	Small earthmover to clear debris or move contaminated solid waste. 	Small earthmover to clear debris or move contaminated solid waste, or dig a trench or hole. 	Removes a layer of grass for disposal. 	Hand tools like a shovel or fork can turn over soil in small plots to bury radioactivity and shield against radiation. 	Small plows attached to small or large vehicles can turn over the soil down to a depth of approximately 6 inches to bury radioactivity and shield against radiation. 	Can remove loose contaminated soil, gravel, dust, leaves, or small debris into on-board storage tank 	Contaminated dust can be removed by wiping with wet towels. 	Removes contaminated dust on or shallow layer of surfaces of rock gardens, trees/foliage, etc. 	Removes contaminated dust on surfaces of rock gardens, patios, roofs, gutters, windows, walls, and other hard materials. 	Used to reduce the amount of low-level waste by assaying 100% of soil or debris.[a] 	Lawn mowers of various size can cut and remove contaminated grass. 	Hand tools like hedge cutters and shears can remove contam-inated foliage. 	Designed to remove leaves and mulch from short grass. 
		ADVANTAGES	Cheap. Requires minimal training.	Fast, efficient with a range of bucket sizes, very effective.	Combination excavator and grading plane useful for breaking up and removing layers.	Large area turf stripper with controlled depth. Removing grass in early response can be very effective at removing contamination	Large quantities available COTS, good control for small plots, DIY.	Large quantities available COTS, good control for medium plots, DIY.	Better control than shovel trucks to remove loose debris.	Large quantities available COTS, effective, minimizes waste, DIY.	Large quantities available COTS, minimizes water use, DIY, Fukushima experience.	Large quantities available COTS, minimizes water use, DIY.	Assay 100% of material, radionuclide discrim., high throughput.	Large quantities available, DIY, collects clippings.	Large quantities available DIY.	DIY, good coverage rate. Designed to handle leaves, twigs, and other small plant debris.
		LIMITATIONS	Low removal rate.	Depth control.	Depth control.	Removal rate.	Dust control, sufficient depth to reduce exposure, best practice procedures.	Dust control, sufficient depth to reduce exposure.	Limited capacity (less than 5000 gallons), availability in numbers.	Exposure, manpower, consistency of results, best practice procedures.	Water collection, manpower, aerosol exposure, best practice procedure.	Water collection, manpower, aerosol exposure, best practice procedure.	Cost-benefit, availability.	Dust control, operator exposure, only removes contamination on grass blades.	Collecting clippings.	May not be effective on grass clippings.
		R&D NEEDS	Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR).	Exposure reduction estimates (LR). Expected uptake of radionuclides into grasses, plants, and trees (LR). Best practice guidance (LR).	Exposure reduction estimates (LR). Expected uptake of radionuclides into grasses, plants, and trees (LR). Best practice guidance (LR).	Survey of inventory (LR). Clarify transport regulations (LR). Decontaminatio n guidance (LR). Best practice guidance (LR).	Data from Fukushima experience (LR). Best practice guidance (LR).	Data from Fukushima experience (LR). Best practice guidance (LR).	Data from Fukushima experience (LR). Best practice guidance (LR).	Cost-benefit analysis (LR). Survey of inventory (LR).	Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR).

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TABLE 3-3-3 Support Goal: Decontamination (gross and final) for Scenario 3

Scenario Description	Summary	Category	Column Number																
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Scenario 3: Hard, horizontal surfaces such as roads, walkways, and parking lots can trap radioactive contamination. Prior studies and experience show that the contamination resides at or very near the surface of such hard materials (less than 1 cm or less than 0.5 inches). What equipment would be useful for removing contamination at the surface? What equipment would be useful in **removing a very shallow depth of paving material**? How does the choice of equipment and method change if many linear miles of surfaces need such treatment?	• Common unresolved issues: (1) Availability of privately-owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow its use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use. • Hard surface removal is very effective, but common unresolved issues are: (1) collecting surface debris, (2) controlling dust/ overspray, (3) controlling the depth of removal to less than 1 cm or less, and (4) small amount of equipment available.	EQUIPMENT	Asphalt Milling Machine.	Floor scabbler.	Scarifier.	Hand-held planers, scabblers, scraper.	Dust control.	Vehicle mounted planer.	Excavators.	Bulldozer.	Pressure washing.	Water jetting vehicles.	Shot blasting.	Emulsion sprayer (liquid asphalt) distributors.	Large chip spreader.	Chemicals to remove concrete coatings.	Remove paving slabs.	Other specialty equipment for concrete removal.	Washing, wiping by hand or machine.
		DESCRIPTION	Asphalt milling machines are typically used for removing tarmac surfaces or pavement. 	Multiple-tipped heads pound surface for very shallow removal. 	Cutting wheel removes shallow surface. Also known as planers, milling machines, or rotary cutters. 	Hand tools used for small- to medium-sized areas or areas that are harder to access. 	Necessary to capture dust generated from surface removal machines. 	Could strip the surface of long linear areas. 	Common construction equipment for digging and handling. 	Common construction equipment that can push broken pavement. 	At highest pressures, can ablate hard porous surfaces (e.g., asphalt, concrete, ceramics, natural stone) 	Cuts the top layers of hard surfaces for removal. 	Iron shot or dry ice scarifies paved surface layer.[a] 	Sprays asphalt and with chip spreader can be used to seal-in-place the contamin-ation. 	Spreads stone chips. Used with sealer distributor to repave road and seal-in-place contamin-ation. 	Use of chemicals to remove coatings and top layers from concrete. 	If contamin-ation of pavers is high, may want to remove pavers without decontam-ination. 	Specialty equipment in road and nuclear industry (e.g., Concrete Shaving by CoreCut removes 1–10 mm per pass).	DIY methods using towels, mops, scrub brushes. Mechanical floor cleaners may be used on interior surfaces to remove contaminated dust. 
		ADVANTAGES	Variable >50 mm, small to medium 500 to 1200 mm.	5-mm surface removal, 20–30 square meters per hour.	5-mm surface removal, 30–150 square meters per hour.	5-mm surface removal, small area hotspot removal. Removes contaminated paint.	60-liter capacity, HEPA filtration and liquid collecting capacity.	Larger coverage rate than hand units, shallow removal depth.	Variable capacity, Large quantities available	Larger coverage with less precise control than smaller shovel trucks, very effective.	Large quantities available COTS, DIY, Fukushima experience. Minimizes water use.	Very effective, Fukushima experience, water collection on some units. Removes surface with depth control.	Very effective, good coverage rate, Fukushima experience. Often has dust control unit,	Large rate of coverage. Fully automated.	Large rate of coverage. Fully automated with conveyors to spread aggregate.	COTS. Designed to remove tough coatings.	Effective, DIY.	Specialized equipment, very effective.	Can be effective on hard,smooth surfaces, large quantities available COTS, DIY, variety of techniques.
		LIMITATIONS	Availability.	Coverage rate, dust control, availability in the numbers needed. Defaces structures.	Dust control, availability in the numbers needed.	Dust control, coverage rate, availability in the numbers needed for roadway surfaces, DIY guidance.	Availability at HEPA rating.	Dust control, availability.	Depth control.	Depth control.	Water collection, manpower, aerosol exposure, best practice procedure.	Very specialized, availability, water collection.	Very specialized, availability, dust control.	Secondary waste from removal of layer, availability.	Availability.	Limited to removal of coatings.	Guidance for use. May also need to remove grout or sand under or between pavers.	Availability, types and variety needs inventory.	No guidance available, best practices undefined.
		R&D NEEDS	Survey of inventory (LR).	Survey of inventory (LR). Compatible dust control options (LR).	Survey of inventory (LR). Compatible dust control options (LR).	Compatible dust control options (LR). Best practice guidance (LR). Survey of inventory (LR).	Best practice guidance (LR). Survey of inventory (LR).	Survey of inventory (LR). Compatible dust control options (LR).	Best practice guidance (LR).	Best practice guidance (LR).	Data from Fukushima experience (LR). Best practice guidance (LR).	Survey of inventory (LR). Compatible dust control options (LR). Best practice guidance (LR).	Survey of inventory (LR). Compatible dust control options (LR). Best practice guidance (LR).	Survey of inventory (LR). Best practice guidance (LR).	Survey of inventory (LR). Best practice guidance (LR).	None identified.	Best practice guidance (LR).	Survey of inventory (LR).	Best practice guidance (LR).

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TABLE 3-3-4 Support Goal: Decontamination (gross and final) for Scenario 4

Scenario Description	Summary	Category	Column Number								
			1	2	3	4	5	6	7	8	9
Scenario 4: As in Scenario 3, prior studies and experience show that contamination on paved surfaces can be effectively reduced by **washing these surfaces with water-based solutions**. What type of equipment can wash many linear miles of these paved surfaces and collect the washings?	• Common unresolved issues are: (1) Availability of privately-owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow its use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use. • Street sweepers are attractive options, but they were not designed to wash the street or collect very small particles. This makes their utility dubious. Studies are necessary to determine efficacy for urban decontamination. • With any method that employs water, controlling runoff (by diverting it from sewer inlets or covering grates) is important and difficult, especially when dumping thousands of gallons of water on an area.	EQUIPMENT	Mini sweeper.	Street sweeper.	Large area pressure washing.	Pressure washing.	Spill barriers/bunds/berms.	Drain covers or diverters.	Agricultural aircraft.	Firefighting aircraft dumpers.	Bambi buckets.
		DESCRIPTION	Smaller scale street sweeper. 	Used to clean dirt, mud, gravel, and small debris from roadways. 	Designed to clean paved areas. 	Common mobile sprayer (less than 4000 psi), gas or electric powered, can provide chemical and physical removal mechanisms for contamination. 	Flexible temporary berms to protect drains, building entryways, and equipment from shallow water.[a] 	Specialty or ad hoc covers can protect intakes or penetrations from contaminated water.[a] 	Crop dusters or top spreaders spread pesticides or fertilizers over large tracts of land. They can similarly spread water-based solutions. 	Designed to fight fires by deluging an area with water from a nearby water source. 	Designed to fight fires by deluging an area with water from a nearby water source. 
		ADVANTAGES	Water or waterless vacuum sweeper.	Water or waterless vacuum sweeper.	50 liters per minute, 1,650-liter tank.	Large quantities available COTS, variable pressure (about 10 liters per minute).	Large quantities available COTS, flexible material for custom applications.	COTS (plugs) or existing infrastructure (diverters), ad hoc materials (wood, polymer sheeting) likely available.	Large coverage rate, versatile aircraft.	Can treat large areas, large volumes (supertanker: 20,000 U.S. gallons).	Large volume capacity (up to 2600 gallons).
		LIMITATIONS	Designed for sand and grit type debris. Some units do not have HEPA filters.	Designed for sand and grit type debris. Some units do not have HEPA filters.	Secondary waste, water recycle cab needed.	Secondary waste, higher pounds per square inch units are limited quantity, small coverage rate.	Shallow waters.	Large number of intakes or penetrations may require custom covers.	Amount of water may be insufficient for goal. Requires trained personnel. Containment of water, access to urban canyons, availability	Gross spreader, availability. Requires trained personnel. The impact of water dropped at elevation can damage structures.	Gross spreader, availability. Requires trained personnel. The impact of water dropped at elevation can damage structures.
		R&D NEEDS	Effectiveness on smaller fallout particles (BE, PE). Water recycle options (LR, BE, PE).	Effectiveness on smaller fallout particles (BE, PE). Water recycle options (LR, BE, PE).	Survey of inventory (LR). Water collection options (LR).	Data from Fukushima experience (LR). Best practice guidance (LR).	Best practice guidance (LR).	Best practice guidance (LR).	Survey of inventory (LR). Guidance on use (LR, BE, PE).	Survey of inventory (LR). Guidance on use (LR, BE, PE).	Guidance on use (LR, BE, PE). Survey of inventory (LR).

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TABLE 3-3-5 Support Goal: Decontamination (gross and final) for Scenario 5

Scenario Description	Summary	Category	Column Number						
			1	2	3	4	5	6	7
Scenario 5: How would the proposed method of addressing the scenarios change **if the contaminated area were close enough to the ocean coastline or other navigable waterway** to use maritime equipment and methods?	• Drainage networks in urban areas are sometimes directed toward nearby waterways. It is unclear what regulations are in place to determine whether water washings must be collected. Drainage networks might be used to dispose of contaminated washings, especially if the area is coastal, where significant dilution factors are possible. In sea and short riverways, inland locations may be more restrictive if the potential to pollute or spread contamination to other areas exists. • Interaction with water treatment works and drinking water supplies must be considered more thoroughly.	EQUIPMENT	Fireboats.	Personal, municipal, and commercial watercraft.	Firefighting aircraft dumpers.	Bambi buckets.	Charge water lines on bridges.	Vehicle bunds.	Amphibious excavators.
		DESCRIPTION	Designed for structures in or adjacent to waterway, but can supply water throughout city via piping. 	Can be used if pumps and hoses are added to the craft. 	Designed to fight fires by deluging an area with water from a nearby water source. 	Designed to fight fires by deluging an area with water from a nearby water source. 	Can be used to immediately decontaminate vehicles exiting a contamination area to keep contamination contained. Fireboats charge standpipe on bridges. 	Can be used to contain wash waters from vehicles (e.g., on a bridge) to reduce contaminated runoff.[a] 	Dredging equipment can be used to remove contaminated sediment from outflows.  
		ADVANTAGES	Pumps 2,000–50,000 liters per minute. Unlimited water supply, regional use.	Existing supply of watercraft.	Can treat large areas, large volumes (supertanker: 20,000 U.S. gallons).	Large volume capacity (up to 2600 gallons).	Strategic location, water supply. Can be coupled to monitoring station.	Portable, collapsible, flexible design, rapid deployment, DYI.	Designed to remove sediment. Can be very effective when coupled to holding vessel for contaminated sediment.
		LIMITATIONS	Water containment. For immediate coastal only. Use as continuous pump for seawater.	Available certified operators, available water pumps, DIY guidance, retrofitability, liability concerns. Limited to immediate coastal coverage.	Gross spreader, availability. Requires trained personnel. The impact of water dropped at elevation can damage structures.	Gross spreader. The impact of water dropped at elevation can damage structures.	Water containment.	More common in some regions (CA, HI, UT) than others. Designed for smaller volumes of water.	Creates large volume of waste. Little control over depth of removal.
		R&D NEEDS	Survey of inventory (LR). Best practice guidance (LR).	Liability concerns (LR). Lessons from previous disasters (e.g., Sandy and Harvey) (LR). Apps used to recruit volunteers (LR). Survey of inventory (LR). Best practice guidance (LR).	Survey of inventory (LR). Best practice guidance (LR).	Guidance on use (LR, BE, PE). Survey of inventory (LR).	Survey of inventory (LR). Best practice guidance (LR). Water collection options (LR).	Guidance on use (LR). Survey of inventory (LR).	Guidance on use (LR). Survey of inventory (LR).

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TABLE 3-3-6 Support Goal: Decontamination (gross and final) for Scenario 6

Scenario 6	Responses						
Question to participants: Do you have other thoughts or specific questions based on your experiences in your geographical area related to this topic?	Top-down approach where workers clean building sides and roofs first, if needed, using water for large structures but with aerosol cross-contamination in mind.	Not all contaminants are easily removed using water. The use of water, with its associated generation of significant volumes of secondary waste, may not be the best option in many situations. Collection of water washings is often very difficult despite best efforts.	The weather could play a major factor in determining where the activity goes. In addition, access restrictions due to abandoned vehicles could cause problems.	Public outcry from defoliation. Need information campaign to inform public of activity.	How do we start decontamin-ation, and where? Liberty RadEx reported importance of stakeholder involvement in decontamination strategy.	Obtaining permission to enter private residences. May need to track the evacuees and obtain permission to enter their premises to monitor or perform decontamination.	Timing is important. If you have broken communities, not coming back after 6 months or so, consider rebuilding vs. cleaning. Assess whether it might be better to turn over the land to developers and let them redevelop into green space, for example. However, this will generate increased amounts of waste.

TABLE 3-3-7 Support Goal Training: Decontamination (gross and final) for Scenarios 1-6

Support Goal Training: Scenarios 1-6	Summary	Responses					
Question to participants: What are your thoughts and recommendations on the **availability of trained human assets and training of the additional assets** likely needed to accomplish the scenarios under this goal? (It is understood that training will be a significant effort and an additional limiting factor in any response scenario. Further, it may need to be addressed more thoroughly in the future, but input is needed to help guide how training guidance should be developed.)	Wide-area radiological contamination incidents are rare, and a response to such an incident will require tremendous human assets. Lessons learned from the cleanup efforts in Japan showed that many thousands of individuals each day are engaged in clean-up activities.	Such decontamination responses require a unified effort with a central chain of command. This is essential to ensure safe decontamination of adjacent areas, and to prevent re-contamination of previously decontaminated areas.	It is also essential that clear objectives be set; a defined end point or “clean-down level” must be decided upon for each location, surface, etc., prior to the start of decontamination. Any remediation or decontamination would need to be legally defensible by the supervising authority.	The Nuclear Regulatory Commission and DOE have training programs for work with radioactive materials. The Environmental Protection Agency has Hazardous Waste Operations and Emergency Response Standard (HAZ-WOPER) for contractors and workers to receive a 40-hour OSHA course that will cover PPE, hazard, and working in a contaminated environment. Then, they receive basic and advanced radiation safety training (as appropriate), and respirator use and care if they use one.	Decontamination of small plots of land may be more cost effective and achievable if undertaken by landowners. Minimal training is required to use a shovel, although respiratory protection against resuspension of material and suitable waste disposal measures would clearly need to be considered as part of any training.	SQEP individuals with radiological experience would be in short supply. Add in the complexities of remediation in unfamiliar working environments, and there are significant conventional and radiological hazards to be aware.	Providing basic radiological training for specialist operators with no radiological experience is likely to be the most cost effective and timely option for ensuring SQEP workers are used on site. Teams would include trained health physicists or monitors to ensure radiological safety of all staff on site. This is common practice on non-nuclear sites for remediation work.

3.4 SUPPORT GOAL: WASTE MANAGEMENT

Businesses and residences over a wide area will generate contaminated solid waste in varying sizes and container types. Solid radioactive waste should be collected for staging and disposal. What types of municipal and commercial equipment can stabilize, contain, store, and transport the radioactive solid waste generated during mitigation and decontamination operations? Examples include using municipal waste garbage trucks and current routes to pick up garbage associated with small-scale (local) operations, and using existing software and procedures developed for the transport of radioactive material to identify preferred routes. Tables 3-4-1 to 3-4-5 present various scenarios related to waste management, possible responses to the scenarios, and possible equipment/technology used in responding, including its advantages, limitations, and R&D needs.

TABLE 3-4-1 Support Goal: Waste Management for Scenario 1

Scenario Description	Summary	Category	Column Number											
			1	2	3	4	5	6	7	8	9	10	11	12
Scenario 1: It is assumed that radioactively contaminated material will be generated in residences as a result of personnel and self-help practices. **How would the individual waste receptacles generated at residences be collected** to avoid an accumulation of radioactively contaminated materials within multi-family units or at the curbside? Does the equipment and method of collection differ for more sparsely distributed suburban areas compared to congested downtown residences?	• Common unresolved issues: (1) Availability of privately-owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow their use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use. • Most items discussed here have large quantities available COTS. Any waste storage container will need to be evaluated for stability against radioactive materials (weight, moisture, leakage), identification and tracking, and potential transport on the highways to avoid repackaging. • Can common trucks transport contaminated materials in compliance with regulations? • There is a need to identify and develop methods of interrogating storage containers to determine radionuclide content.	EQUIPMENT	Waste skip truck.	1-ton waste bags.	13.2-gallon/50-liter containers.	55-gallon/200-liter drums.	Standard garbage trucks.	Tractor trailer.	Parcel trucks.	Liquid waste in drains or sewers.	Bulldozers, backhoes, front loaders, bobcats, etc.	Dump truck.	Quarry wagon.	Tagging and tracking.
		DESCRIPTION	Storage bins designed for easy hauling. May be used for neighborhood or business unit waste. 	Flexible, durable storage units for contaminated loose solids such as dirt and other solid waste. 	Households or offices may segregate suspected radioactive waste. 	Sturdy drums designed for hazardous waste and transport. 	Devoted trucks for hauling radioactive waste. Monitors could potentially be added to the truck to segregate at the street. 	Large-volume storage and transport. 	Medium-volume storage and transport. 	Liquid waste will invade sewers, so anticipate this and handle contaminated waters at the outflow or waste water plant. 	Can relocate waste. Distance and shielding reduce dose to worker. 	Hauls large volumes of containers or waste. 	Huge capacity transport. 	Tags to identify and track waste container contents. 
		ADVANTAGES	Large quantities available COTS.	Durable, number of suppliers, Fukushima experience. Many designed for easy transport.	Large quantities available COTS.	Large quantities available COTS.	Opportunity to monitor and segregate at street or at transfer stations.	Large quantities available COTS.	Large quantities available COTS.	Ubiquitous urban network.	Large quantities available COTS.	Large quantities available COTS.	Huge volumes.	Established method, Fukushima experience.
		LIMITATIONS	Not designed for hazardous materials.	Immediate availability in numbers needed.	Repackaging requirements, small volume.	Small volume.	Dust control.	Not designed for hazardous materials. Dose to driver on routes.	Not designed for hazardous materials. Dose to driver on routes.	Contaminating outflows. May require additional unit operation to pretreat contaminated waters.	Dose to driver. Hermetically sealed cabs are not COTS.	Dose to driver on routes.	Availability, approved roadways. Hermetically sealed cabs are not COTS.	Tracking system.
		R&D NEEDS	Method to monitor each bin or bins (LR, BE, PE). Calculated dose to driver on routes (LR). Decontamination guidance (LR).	Method to monitor each bag or unit (LR, BE, PE). Guidance on use (LR). Survey of inventory (LR).	Guidance on use (LR).	Method to monitor each drum or drums (LR, BE, PE). Guidance on use (LR). Decontamination guidance (LR).	Dose to driver on routes (LR). Decontamination guidance (LR).	Dose to driver on routes (LR). Decontamination guidance (LR).	Dose to driver on routes (LR). Decontamination guidance (LR).	Water treatment methods (BE, PE).	Decontamination guidance (LR). Dose to driver on routes (LR). PPE needs to be addressed (LR). Cab design or retrofit for contaminated environments (LR and/or BE, PE).	Dose to driver on routes (LR). Decontamination guidance (LR).	PPE needs to be addressed (LR). Cab design or retrofit for contaminated environments (LR and/or BE, PE). Dose to driver on routes (LR). Decontamination guidance (LR).	Guidance on use (LR).

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TABLE 3-4-2 Support Goal: Waste Management for Scenario 2

Scenario Description	Summary	Category	Column Number									
			1	2	3	4	5	6	7	8	9	10
Scenario 2: How would the response to Scenario 1 differ if the radioactively contaminated material is generated by local businesses as a result of self-help decontamination? **How would the individual waste receptacles generated by local businesses be collected** to avoid an accumulation of radioactively contaminated materials in multi-business units or curbside? Do the equipment and method of collection differ for more sparsely distributed suburban areas compared to congested downtown businesses?	• Many items discussed in Scenario 1 also apply here (availability, unrestricted use after event, transport regulations, monitoring package). • There may be better opportunity for businesses to follow recommended practices to segregate and package waste to avoid additional effort. That is, businesses can be more easily incentivized and held accountable for correct disposal of such waste than individuals. However, it is also more likely that businesses will hire contractors to do the work. Businesses tend to have large waste containers that could be used with the frequency of collection increased. • Need to consider approach of collecting all garbage as usual and monitoring or segregating contaminated garbage per existing procedures at transfer stations and waste sites. • There is a need to identify and develop methods of interrogating storage containers to determine radionuclide content.	EQUIPMENT	Waste skip truck.	1-ton waste bags.	13.2-gallon/ 50-liter containers.	55-gallon/ 200-liter drums.	Standard garbage trucks.	Tractor trailer.	Parcel trucks.	Liquid waste in drains or sewers.	Dump truck.	Quarry wagon.
		DESCRIPTION	Storage bins designed for easy hauling. May be used for neighborhood or business unit waste. 	Flexible, durable storage units for contaminated loose solids such as dirt and other solid waste. 	Households or offices may segregate suspected radioactive waste. 	Sturdy drums designed for hazardous waste and transport. 	Devoted trucks for hauling radioactive waste. Monitors could potentially be added to the truck to segregate at the street. 	Large-volume storage and transport. 	Medium-volume storage and transport. 	Liquid waste will get into sewers, so perhaps design unit operation to anticipate this and handle contaminated waters at the plant. 	Hauls large volumes of containers or waste. 	Huge capacity transport. 
		ADVANTAGES	Large quantities available COTS.	Durable, number of suppliers, Fukushima experience. Many designed for easy transport.	Large quantities available COTS.	Large quantities available COTS.	Opportunity to monitor and segregate at street or at transfer stations.	Large quantities available COTS.	Large quantities available COTS.	Ubiquitous urban network.	Large quantities available COTS.	Huge volumes.
		LIMITATIONS	Not designed for hazardous materials.	Immediate availability in numbers needed.	Repackaging requirements, small volume.	Small volume.	Dust control.	Not designed for hazardous materials. Dose to driver on routes.	Not designed for hazardous materials. Dose to driver on routes.	Contaminating outflows.	Dose to driver on routes.	Availability, approved roadways. Hermetically sealed cabs are not COTS.
		R&D NEEDS	Method to monitor each bin or bins (LR, BE, PE). Calculated dose to driver on routes (LR). Decontamination guidance (LR).	Method to monitor each bag or unit (LR, BE, PE). Guidance on use (LR). Survey of inventory (LR).	Guidance on use (LR).	Method to monitor each drum or drums (LR, BE, PE). Guidance on use (LR). Decontamination guidance (LR).	Dose to driver on routes (LR). Decontamination guidance (LR).	Dose to driver on routes (LR). Decontamination guidance (LR).	Dose to driver on routes (LR). Decontamination guidance (LR).	Water treatment methods (BE, PE).	Dose to driver on routes (LR). Decontamination guidance (LR).	PPE needs to be addressed (LR). Cab design or retrofit for contaminated environments (LR and/or BE, PE). Dose to driver on routes (LR). Decontamination guidance (LR).

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TABLE 3-4-3 Support Goal: Waste Management for Scenario 3

Scenario Description	Summary	Category	Column Number										
			1	2	3	4	5	6	7	8	9	10	11
Scenario 3: **If accumulated radioactively contaminated waste is being collected at staging locations (e.g., parks and common grounds),** what types of containers can be used to collect the waste receptacles and protect the public from transport of contaminated particles (e.g., through resuspension of breached receptacles)?	• Common unresolved issues: (1) Availability of privately-owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow their use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use. • Estimates of dose to the public from nearby staging locations are needed. • Security and ruggedness of containers to weather (rain, snow, heat, ultraviolet light) at staging locations is an issue. • Guidance on how to predetermine potential staging locations is needed.	EQUIPMENT	Freight containers (lockable).	Roll-on/roll-off containers.	55-gallon/ 200-liter drums.	Large tanks.	Cargo ships.	1-ton waste bags.	Local premises.	Intermediate bulk containers (IBCs).	Barges.	Cardboard boxes.	Temporary lagoons.
		DESCRIPTION	Covered and transportable containers. 	Covered and transportable containers. 	Sturdy drums designed for hazardous waste and transport. 	Any number of tank sizes available or in use for storage. 	Huge capacity 	Flexible, durable storage units for contaminated loose solids such as dirt and other solid waste. 	Town halls, sports stadiums, postal depots, etc., may be used to stage waste. 	Medium-sized container for liquids. 	Huge capacity for storage and transport. 	Affordable container for dry, blunt, rigid objects. 	Huge capacity for liquid storage.[a] 
		ADVANTAGES	Large quantities available COTS.	Large quantities available COTS.	Large quantities available COTS.	Huge capacity.	Huge capacity.	Durable, a number of suppliers, Fukushima experience. Many designed for easy transport.	Local use, large quantities available, network.	Mass produced, easily transported, easily stacked. Compatible with pumps and mixers. Fukushima experience.	Huge capacity.	Large quantities available COTS.	Common to hydraulic fracturing, evaporation.
		LIMITATIONS	Not designed for hazardous materials.	Not designed for hazardous materials.	Small volume.	Availability, onsite construction period.	Availability.	Immediate availability in numbers needed.	Security, public perception.	Designed for liquid waste.	Few plans on eventual destination.	Not rugged or secure.	Attract wildlife.
		R&D NEEDS	Method to monitor each bin or container (LR, BE, PE). Calculated dose to driver on routes (LR). Decontamination guidance (LR).	Method to monitor each bin or container (LR, BE, PE). Calculated dose to driver on routes (LR). Decontaminati on guidance (LR).	Method to monitor each drum or drums (LR, BE, PE). Guidance on use (LR). Decontamination guidance (LR).	Survey of inventory (LR).	Survey of inventory (LR).	Method to monitor each bin or bins (LR, BE, PE). Guidance on use (LR).	Guidance on use (LR).	Method to monitor each bin or bins (LR, BE, PE). Guidance on use (LR).	Survey of inventory (LR).	Guidance on use (LR).	Survey of inventory (LR). Guidance on use (LR).

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TABLE 3-4-4 Support Goal: Waste Management for Scenario 4

Scenario 4	Responses						
Question to participants: Do you have other thoughts or specific questions based on your experiences in your geographical area related to this topic?	It is difficult to envision a scenario, where a family or the public will be present in an area, if the radiation or contamination levels are such that their waste will generate a significant secondary hazard to others.	Use normal waste bins, and then monitor each truckload for gross contamination and manage that.	Apartment and multi-family unit residents would probably be more reluctant to participate in cleanup work, and would instead rely on apartment managers and property owners to perform the work.	Monitor garbage at landfill entry or transfer site entry like current garbage and recycled material.	Not understanding the waste container requirements during generation of waste leads to an inevitable re-sizing process to make waste fit new containers.	Regular garbage or parcel delivery teams would know the area, the routes that are accessible by truck are SQEP for manual handling, and with health physics support would be aware of the radiological hazards.	We need to understand DOT regulations for transport (considering everything might be contaminated). If transport occurs within the contaminated area, does DOT regulations matter?

TABLE 3-4-5 Support Goal Training: Scenarios 1-4

Support Goal Training: Scenarios 1-4	Summary	Responses					
Question to participants: What are your thoughts and recommendations about the **availability of trained human assets and training additional assets** to accomplish the scenarios under this goal? (Training will be a significant effort and an additional limiting factor in any response. It may need to be addressed more thoroughly in the future, but input is needed to help guide how training guidance should be developed.)	Wide-area radiological contamination incidents are rare, and a response to such an incident will require tremendous human assets. Lessons learned from the cleanup efforts in Japan showed that many thousands of individuals each day are engaged in cleanup activities.	Legislation requires employers to ensure their workforce is suitably trained for any tasks they are required to perform.	Training on waste minimization and radiation safety would allow members of the public to make an effective contribution to the cleanup operations.	The Nuclear Regulatory Commission and DOE have training programs for work with radioactive materials. The Environmental Protection Agency has HAZWOPER for contractors and workers to receive a 40-hour OSHA course that will cover PPE, hazard, and working in a contaminated environment. Then, they receive basic and advanced training on radiation safety (as appropriate), and respirator use and care if they use one.	Waste facilities are well regulated and controlled in comparison to hands-on decontamination work. With the right technical experts and SQEP operators, a waste facility is relatively straightforward to operate and involves limited training of new staff in unfamiliar roles.	Running a waste facility is a complex task involving multiple experts including a site manager, radioactive waste adviser, forklift operators, HP monitors, a Dangerous Goods Adviser, and an Environmental Consultant. It should be given equal consideration to the actual cleanup.	In Nevada, they specifically registered and marked waste trucks would haul contaminated waste to Nevada National Security Site Area 5 for sorting and disposal. Those drivers and workers would need basic radiation protection training, dosimetry, and PPE.

3.5 SUPPORT GOAL: CONTAINMENT OF WASTEWATER AND OTHER WASTES

First responders will likely use water to extinguish fires that may be generated during a radioactive release. Water may also be used to reduce radiation levels to early responders and subsequent response teams. Ideally, the water could be collected and treated at the point of use. However, we may need to collect, divert, and store generated radioactively contaminated waters for proper treatment and disposal. What types of municipal and commercial equipment can collect, contain, and transport liquid wastes and other wastes generated after a radioactive release? Examples include portable tanks and storage bladders, barges, tanker trucks, railroad tank cars, fixed tank farms such as those at refineries, the storm sewer, and sewer water storage tunnels and reservoirs. Tables 3-5-1 to 3-5-8 present various scenarios related to containment of wastewater and other wastes, possible responses to the scenarios, and possible equipment/technology used in responding, including its advantages, limitations, and R&D needs.

TABLE 3-5-1 Support Goal: Containment of Wastewater and Other Wastes for Scenario 1

Scenario Description	Summary	Category	Column Number							
			1	2	3	4	5	6	7	8
Scenario 1: What types of **barriers (e.g., sandbags and berms) are available to collect water** generated during its large-scale use (hundreds of thousands to millions of gallons) **over a small urban footprint** (for example, a square city block)?	• Inevitable leakage of some waters is a common problem for these technologies. • Many of the items listed here have large quantities available COTS. • Knowledge of the topography of the terrain will be essential to contain large volumes of water. • Guidance on their specific use is lacking. • Although many cities have GIS sewer maps, guidance is needed on how to best apply these in a radiological contamination incident to achieve the goals of containment. • Knowledge of whether sewer lines can be plugged to hold water in an individual neighborhood or block is lacking.	EQUIPMENT	Spill barriers/bunds/berms.	Drain covers or diverters.	Sandbags.	Flood control barriers.	Inflatable tube barriers.	Inflatable pipe and sewer plugs.	Pumps and piping.	Sewer lines.
		DESCRIPTION	Flexible temporary berms to protect drains, building entryways, and equipment from shallow water.[a] 	Specialty or ad hoc covers can protect intakes or penetrations from contaminated water.[a] 	Effective flood control achieved by building a wall of stacked bags. 	Emergency barriers supplied worldwide during emergencies to control and contain water. 	Inflatable PVC tubes to contain/divert water.[b] 	Inflatable plugs for plugging sewer lines. 	System of pumps and piping to move water from one location to another for collection or storage.[c] 	Sewers can be plugged to isolate contaminated waters in a specific location.[d] 
		ADVANTAGES	Large quantities available COTS, flexible material for custom applications, DIY	COTS (plugs) or existing infrastructure (diverters), DIY. Ad hoc materials (wood, polymer sheeting) likely available.	Large quantities available COTS, DIY.	Several suppliers (e.g., HESCO, Hydro-Response, Lester Solutions, BigBags USA), rapid setup. Designed for emergency deployment. Proven for flood control.	Rapid deployment.	Large quantities available COTS, individual control of piping. Isolates water.	Large quantities available COTS, various sizes of pumps and piping.	Could potentially isolate water for subsequent treatment or transport.
		LIMITATIONS	For shallow waters, requires flat surface to limit water intrusion.	Large number of intakes or penetrations may require custom covers.	Labor intensive. Need to haul necessary fill material.	Need to haul necessary fill material.	Availability.	Knowledge of piping system for effective water diversion.	Availability of larger pumps.	Unsure of extent of capability (trunk lines, mains, sub-main, branches).
		R&D NEEDS	Best practice guidance (LR).	Best practice guidance (LR).	Guidance on use (LR).	Guidance on use (LR).	Survey of inventory (LR). Guidance on use (LR).	Strategy for use (LR). Existence of sewer and topography maps (LR).	Guidance on use (LR). Survey of inventory (LR).	Survey of sewer network mapping and capabilities (LR).

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TABLE 3-5-2 Support Goal: Containment of Wastewater and Other Wastes for Scenario 2

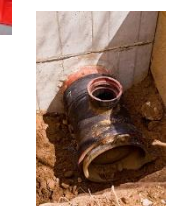
Scenario Description	Summary	Category	Column Number									
			1	2	3	4	5	6	7	8	9	10
Scenario 2: What types of **barriers (for example, sandbags and berms) are available to collect water** generated during its large-scale use (millions of gallons) **over a large urban footprint** (for example, 10 square city blocks)?	• Inevitable leakage of some waters is a common problem for these technologies. • Many of the items listed here are largely available as COTS. • Knowledge of the topography of the terrain will be essential to contain large volumes of water. • Guidance on their specific use is lacking. • Whether all major cities have GIS sewer maps is unknown. • Knowledge of whether sewer lines can be plugged to hold water in an individual neighborhood or block is lacking.	EQUIPMENT	Spill barriers/bunds/berms.	Drain covers or diverters.	Sandbags.	Flood control barriers.	Inflatable tube barriers.	Inflatable pipe and sewer plugs.	Pumps and piping.	Flood barriers.	Sewer lines.	Jersey barriers.
		DESCRIPTION	Flexible temporary berms to protect drains, building entryways, and equipment from shallow water.[a] 	Specialty or ad hoc covers can protect intakes or penetrations from contaminated water. [a] 	Effective flood control achieved by building a wall of stacked bags. 	Emergency barriers supplied worldwide during emergencies to control and contain water. 	Inflatable PVC tubes to contain/divert water. 	Inflatable plugs for plugging sewer lines. 	System of pumps and piping to move water from one location to another for collection or storage.[b] 	Can be used to limit water intrusion.[c] 	Sewers can be plugged to isolate contaminated waters in a specific location.[d] 	Create a temporary dike with Jersey barriers or lined k-rails to divert water to a central location. 
		ADVANTAGES	Large quantities available COTS, flexible material for custom applications, DIY.	COTS (plugs) or existing infrastructure (diverters). Ad hoc materials (wood, polymer sheeting) likely available.	Large quantities available COTS, DIY.	Several suppliers (e.g., HESCO, Hydro-Response, Lester Solutions, BigBags USA), rapid setup. Designed for emergency deployment. Proven for flood control.	Rapid deployment.	Large quantities available COTS, individual control of piping, isolates water.	Large quantities available COTS, various sizes of pumps and piping.	Plastic portable flood barrier.	Could potentially isolate water for subsequent treatment or transport.	Large quantities available COTS, ad hoc construction.
		LIMITATIONS	For shallow waters, requires flat surface to limit water intrusion.	Large number of intakes or penetrations may require custom covers.	Labor intensive. Need to haul necessary fill material.	Need to haul necessary fill material.	Availability.	Knowledge of piping system for effective water diversion.	Availability of larger pumps.	Availability, for shallow waters.	Unsure of extent of capability (trunk lines, mains, sub-mains, branches)	For shallow waters.
		R&D NEEDS	Best practice guidance (LR).	Best practice guidance (LR).	Guidance on use (LR).	Guidance on use (LR).	Survey of inventory (LR). Guidance on use (LR).	Strategy for use (LR). Existence of sewer and topography maps (LR).	Guidance on use (LR). Survey of inventory (LR).	Survey of inventory (LR). Guidance on use (LR).	Strategy for use (LR). Survey of sewer network mapping and capabilities (LR).	Guidance of use (LR).

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TABLE 3-5-3 Support Goal: Containment of Wastewater and Other Wastes for Scenario 3

Scenario Description	Summary	Category	Column Number					
			1	2	3	4	5	6
Scenario 3: Do the answers to Scenarios 1 and 2 differ if the **water is used to wash down vertical surfaces** as opposed to horizontal surfaces?	• Inevitable leakage of some waters is a common problem for these technologies. • Many of the items listed here are largely available as COTS. • Knowledge of the topography of the terrain will be essential to contain large volumes of water. • Guidance on their specific use is lacking. • Whether all major cities have GIS sewer maps is unknown. • Knowledge of whether sewer lines can be plugged to hold water in an individual neighborhood or block is lacking.	EQUIPMENT	Portable containment bunds.	Pumps and piping.	Automated window/ building washers.	Gutter drains.	Flood control barriers.	Diapering around each floor of building.
		DESCRIPTION	Designed for barrel, tank, or vehicle spills.[a] 	System of pumps and piping to move water from one location to another for collection or storage.[b] 	Decontaminates windows and walls. 	Capturing water from gutters allows for wash down of roofs. 	Pushed against a wall, the barriers can force building runoff into a containment area. 	Technology may exist to create barrier around building façade at each floor to contain runoff. (no picture available).
		ADVANTAGES	Portable, collapsible, flexible design, rapid deployment, DIY.	Large quantities available COTS, various sizes of pumps and piping.	Less water, remote operation. Treats irregular surfaces.	Large quantities available use and COTS, efficient collection of water.	Several suppliers (e.g., HESCO, Hydro-Response, Lester Solutions, BigBags USA), rapid setup. Designed for emergency deployment. Proven for flood control.	Isolate floors for easier handling of water. Horizontal washing.
		LIMITATIONS	Designed for smaller volumes of water.	Availability of larger pumps and pipes.	Limited COTS, decontamination efficacy unknown, water collection system needed.	Needs to integrate water storage and treatment.	Quality of seal against building.	Unknown availability and capability.
		R&D NEEDS	Guidance on use (LR). Survey of inventory (LR).	Guidance on use (LR). Survey of inventory (LR).	Survey of inventory (LR). Test efficacy for rad (BE, PE). Integrate water capture system (LR, BE, PE).	Guidance on use (LR).	Guidance on use (LR).	Survey of inventory or development needs (LR).

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TABLE 3-5-4 Support Goal: Containment of Wastewater and Other Wastes for Scenario 4

Scenario Description	Summary	Category	Column Number								
			1	2	3	4	5	6	7	8	9
Scenario 4: If the water is collected at the point of use, **what containers, vessels, or facilities are available to store the water** generated in Scenarios 1 through 3 until it can be processed or transported?	• Common unresolved issues: (1) Availability of privately-owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow its use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use. (3) Need for a sufficient available footprint to accommodate storage unit and need for approval for its siting, construction, and operation. • Many of the water storage options presented here are explained in more detail in EPA 817-B-12-002.	EQUIPMENT	Large tanks.	Intermediate bulk containers (IBCs).	Road tankers.	Baker trucks.	Locally constructed, lined lagoons or pools.	Pumps and piping.	Inflatable pipe and sewer plugs.	Fuel/water bladders.	Sewer lines.
		DESCRIPTION	Any number of tank sizes available or in use for liquid storage. 	Medium-sized container for liquids. 	Allow for immediate transport of water following filling. 	Can be used to store or treat water as an ad hoc filter bed. https://www.bakercorp.com/en-us/	Local structure for containing water.[a] 	System of pumps and piping to move water from one location to another for collection or storage.[b] 	Using sewer flow maps, plug the sewer lines to force water to a location for collection and treatment. 	Flexible bladders for holding water or fuel.[a] 	Sewers can be plugged to isolate contaminated waters in a specific location.[c] 
		ADVANTAGES	Huge capacity, Fukushima experience.	Mass produced, easily transported, easily stacked. Compatible with pumps and mixers, Fukushima experience.	Large quantities available, network, existing operators, large volume (more than 10,000 gallons).	Commonly used, large capacity.	Huge capacity, local, versatile design, prior knowledge in chemical industry.	Large quantities available COTS, various sizes of pumps and piping.	Large quantities available COTS, individual control of piping, isolates water.	Large capacity (more than 200,000 gallons), rapid deployment.	Potentially isolate water for subsequent treatment or transport.
		LIMITATIONS	Slow construction.	Smaller volume (up to ~550 gallons).	Approved routes, availability.	Availability.	Siting. Attracts wildlife.	Availability of larger pumps and pipes.	Knowledge of piping system for effective water diversion.	Availability.	Unsure of extent of capability (trunk lines, mains, sub-main, branches).
		R&D NEEDS	Guidance for use (LR).	Method to monitor each bin or bins (LR, BE, PE). Guidance on use (LR).	Clarify transport regulations (LR). Decontamination guidance (LR).	Survey of inventory (LR). Clarify transport regulations (LR). Decontamination guidance (LR). Guidance for use as filter bed (LR, BE, PE).	Design guidance (LR).	Guidance on use (LR). Survey of inventory (LR).	Strategy for use (LR). Existence of sewer and topography maps (LR).	Survey of inventory (LR).	Survey of sewer network mapping and capabilities (LR).

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TABLE 3-5-5 Support Goal: Containment of Wastewater and Other Wastes for Scenario 5

Scenario Description	Summary	Category	Column Number								
			1	2	3	4	5	6	7	8	9
Scenario 5: If the **water penetrates the sewer system** and can be diverted at a downstream collection site (e.g., just prior to entering the water reclamation district or wastewater treatment plant), **what containers, vessels, or facilities are available to store the water until it can be processed or transported?**	• Common unresolved issues: (1) Availability of privately-owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow its use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use. (3) Need for an approved storage footprint to accommodate storage unit and need for approval for its siting, construction, and operation.	EQUIPMENT	Bund liners.	Fuel/water bladders.	Dracone barge.	Huge tanks.	Locally constructed, lined lagoons or pools.	Pumps and piping.	Frack water tanks.	Baker trucks.	Railcars.
		DESCRIPTION	Designed to store water until it has been treated or evaporates.[a] 	Flexible bladders to hold water.[b] 	United Kingdom (UK) product to transport liquids or contain oil spills and tow it away. http://www.trelleborg.com/en/our--solutions/flexible--containment--solutions	Used to store liquids for distribution or treatment. 	Local structure for containing water. 	System of pumps and piping to move water from one location to another for collection or storage.[c] 	Designed to hold water onsite until treatment.[b] 	Can be used to store or treat water as an ad hoc filter bed. https://www.bakercorp.com/en-us/	Can transport contaminated water. 
		ADVANTAGES	Liners for a pit, natural evaporation.	Large capacity (more than 200,000 gallons), rapid deployment.	Highly portable when empty. Deployed for emergency spills. Huge capacity, rugged.	Enormous capacity.	Huge capacity, local, versatile design, prior experience in chemical industry.	Large quantities available COTS, various sizes of pumps and piping.	Huge capacity, evaporation.	Commonly used, large capacity.	Large network and variety of rolling stock for hauling, hazardous transport ongoing.
		LIMITATIONS	Siting, availability. Attracts wildlife.	Availability.	Availability.	Availability.	Siting. Attracts wildlife.	Availability of larger pumps.	Siting, availability. Attracts wildlife.	Approved routes, availability.	Agreements for use, no predetermined destination, availability of tanker cars.
		R&D NEEDS	Survey of inventory (LR).	Survey of inventory (LR).	Survey of inventory (LR).	Survey of inventory (LR).	Design guidance (LR).	Guidance on use (LR). Survey of inventory (LR).	Survey of inventory (LR).	Survey of inventory (LR). Clarify transport regulations (LR). Decontamination guidance (LR). Guidance for use as filter bed (LR, BE, PE).	Survey of inventory (LR). Clarify transport regulations (LR). Decontamination guidance (LR).

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TABLE 3-5-6 Support Goal: Containment of Wastewater and Other Wastes for Scenario 6

Scenario Description	Summary	Category	Column Number					
			1	2	3	4	5	6
Scenario 6: What other methods are available for diverting water to avoid the sewer system and collect water at a central location?	• Common unresolved issues: (1) Availability of privately-owned equipment. It may already be in commercial or private use, or owners may be reluctant to allow its use in a radioactive environment without prior agreements in place. (2) Ability to decontaminate equipment afterward for unrestricted use.	EQUIPMENT	Temporary piping.	Pumps.	Inflatable pipe and sewer plugs.	Vacuum trucks (water use).	Storm water bunding.	Baker trucks.
		DESCRIPTION	Install pipes and pumps to move water at time of need. 	Large-capacity pumps down to sump pumps can move water through existing or ad hoc piping. 	Using sewer flow maps, plug the sewer lines to force water to a location for collection/treatment. 	Can remove contaminated water and transport to a temporary storage unit. 	Can divert water from inlets. 	Can be used to store or treat water in an ad hoc filter bed. https://www.bakercorp.com/en-us/
		ADVANTAGES	Large quantities available COTS.	Pumps of varying size COTS, locally distributed depending on size. Thousands, hundreds, or tens of gallons per minute.	Well-known technique, effective at diverting water.	Common equipment.	Portable, collapsible, flexible design, rapid deployment.	Commonly used, large capacity.
		LIMITATIONS	Preplanned collection points, available plumbers and pumps.	Large pump availability.	No existing strategy or plan.	Limited capacity (less than 5000 gallons), availability in numbers.	Limited volume, available COTS.	Approved routes, availability.
		R&D NEEDS	Guidance for use (LR).	Guidance on use (LR). Survey of inventory (LR).	Strategy for use (LR). Existence of sewer and topography maps (LR).	Survey of inventory (LR). Clarify transport regulations (LR).	Guidance on use (LR). Survey of inventory (LR).	Survey of inventory (LR). Clarify transport regulations (LR). Decontamination guidance (LR). Guidance for use as filter bed (LR, BE, PE).

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TABLE 3-5-7 Support Goal: Containment of Wastewater and Other Wastes for Scenarios 7 and 8

Scenario Description	Summary	Category	Column Number				
			1	2	3	4	5
Scenario 7: Are there **existing trenches, dams, retention ponds, community reservoirs**, etc., available to collect water? Are there paths for directing the wash water from its point of use to these existing collection systems?	• Knowledge of the topography of the terrain will be essential to contain large volumes of water. • Guidance on their specific use is lacking. • It is not known if all major cities have GIS sewer maps. • We need to know whether sewer lines can be plugged to hold water in an individual neighborhood or block.	EQUIPMENT	Inflatable pipe and sewer plugs.	Underground garages.	Underground rainwater storage tunnels or reservoirs.	Local retention/detention ponds.	Lined waterways for flood control.
		DESCRIPTION	Using sewer flow maps, plug the sewer lines to force water to a location for collection/treatment. 	Divert water to underground garages for storage. 	Some cities have enormous tunnels or reservoirs designed to temporarily hold water during heavy rains. 	Provides temporary flood control, but may be used to hold contaminated water until processed. 	Arid regions (esp.) may have concrete-lined flood control waterways where water can be diverted from the sewer system and stored until treated. 
		ADVANTAGES	Well-known technique, effective at diverting water.	Distributed network, large capacity.	Enormous volumes (hundreds of millions of gallons) using existing capabilities.	Large network, large capacity, existing inflow and outflow systems, strategic point to process water.	Enormous capacity, existing network and protocols.
		LIMITATIONS	No existing strategy or plan.	Availability, engineering assessment for use, decontamination for return to service.	Specialized and local.	Method to divert waters, controlling outflow.	Decontamination, regionally located.
		R&D NEEDS	Strategy for use (LR). Existence of sewer and topography maps (LR).	Strategy for use (LR). Survey of inventory (LR). Decontamination guidance (LR).	Strategy for use (LR). Survey of inventory (LR). Decontamination guidance (LR).	Strategy for use (LR). Survey of inventory (LR).	Strategy for use (LR). Survey of inventory (LR). Decontamination guidance (LR).
Scenario 8: Question to participants: Do you have other thoughts or specific questions based on your experiences in your geographical area related to this topic?		RESPONSES	Research ways to filter large volumes of liquid waste along drainage routes or collection points.	Experience in UK has shown that minimal use of water is best, given difficulty in containing and disposal.	Water jetting practices minimize water use.	Due to reliance on surface and groundwater sources for drinking water and the difficulty of managing and ensuring containment of large volumes of contaminated water, the use of open water retention schemes is very unlikely to be acceptable.	Some emergency planning documents suggest that it is best to allow contaminated waters to reach the water treatment plants and then treat them. However, treatment plant operators have little guidance or knowledge of effects of contaminated waters on plant operations.

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TABLE 3-5-8 Support Goal Training: Containment of Wastewater and Other Wastes for Scenarios 1-8

Support Goal Training: Scenarios 1-8	Summary	Responses
Question to participants: What are your thoughts and recommendations on **availability of trained human assets and training of additional assets** that will likely be needed in order to accomplish the scenarios under this goal? (Training will be a significant effort and an additional limiting factor in any response. It may need to be addressed more thoroughly in the future, but input is needed to help guide how training guidance should be developed.)	Wide-area radiological contamination incidents are rare, and a response to such an incident will require tremendous human assets. Lessons learned from the cleanup efforts in Japan showed that many thousands of individuals each day are engaged in clean-up activities.	Large-scale wastewater management would require specialist with floodwater management expertise supported by health physics monitors and decommissioning specialists.

4 RANKING THE EQUIPMENT

Using Tables 3-1-1 through 3-5-8, we gathered responses from the various SMEs to rank the equipment. To do so, participants were asked to consider the listed R&D needs and determine what equipment they would prioritize based on likely use *and* need for additional knowledge of its use, function, or efficacy. They ranked these items according to what would provide the most benefit from additional R&D (rank 1) to less benefit (rank 3). Importantly, the results of the rankings may be used to prioritize future work, including best practices, operational guides, and work to adapt the equipment for radioactive contamination scenarios. Organized by Support Goal, these were the technologies ranked highest by the SMEs.

Survey and Monitoring

- Small vehicles with commercial gamma detector.
- Smart phones as radiation detectors.
- Drones equipped with gamma cameras.
- USB-type dosimeters.
- Air filters from home and vehicles for monitoring resuspended contamination.
- Radiation monitors on taxis, buses, ambulances, delivery vehicles, etc., with GPS tracking.
- Speedbump detectors to monitor vehicles.
- Portal or other stationary monitors for vehicles.

Mitigation of Received Dose to First Responders

- Street sweeper (retrofitted) with on-board detectors and GPS tracking.
- Portable water trailer to wash street.
- Soil stabilizer spray systems to control airborne dust.
- Chip sealer (emulsion) distributor to cover roads and reduce resuspension hazard.
- Intermediate bulk container with polymer (paint) sprayer to cover streets.
- Mobile spray unit to cover surfaces with films.

Support Goal: Decontamination (gross and final)

- Salt spreaders to improve decontamination.
- Pressure washer systems for decontamination.
- Mobile water filtration systems for captured waters.
- Wash units used for freight and passenger trains.
- Best practices for cleaning hospitals and commercial nuclear power plants.
- Automated window/building washers.

Waste Management

- Distributed waste skippers/freight containers for contaminated trash.
- 1-ton solid waste bags for containment and transport from residences and businesses.

- Tagging and tracking systems for waste bags and units.
- Procedures for qualifying transport of waste via freight container.

Containment of Wastewater and Other Wastes

- Drain covers and flood control barriers to divert and collect water.
- Lined lagoons for storage of contaminated water.
- Monitors for sewer lines.
- Pumps and ad hoc piping to transfer contaminated water from
  - sewer lines to container trucks or rail tankers
  - reservoir to rail tankers.

5 EXISTING GUIDANCE

Table 5-1 lists some existing documents and information that cover topics relevant to this report.

TABLE 5-1 Existing Guidance

Topic	Resource
Technical Documents	• The New York (NY) Metropolitan Transportation Authority (MTA) worked with Lawrence Livermore National Laboratory to produce a guidance document on the response and recovery of the MTA system following a radioactive release event. The topics covered in the report may be useful for other critical infrastructure and urban environments in terms of detection, dose mitigation, containment, decontamination, and training. Please contact M. Gemelli, NY MTA for access to the document (classified as Official Use Only). • Individual city, county and regional radiological response plan documents often completed in areas that have nuclear power stations. • *Planning Guidance for Response to a Nuclear Detonation*, Federal Emergency Management Agency, June 2010 (for instance, see Table 2.2, Mission Oriented Detector Selection, in that document). https://www.fema.gov/media-library-data/20130726-1821-25045-3023/planning_guidance_for_response_to_a_nuclear_detonation___2nd_edition_final.pdf • Wagner E., Sorom R., and Wiles L., "Radiation Monitoring for the Masses," *Health Phys*. 2016 110(1):37–44. Provides an overview of methods of monitoring people (and their environment) using conventional, unconventional, and upcoming measurement devices. • *Containment and Disposal of Large Amounts of Contaminated Water: A Support Guide for Water Utilities*, Office of Water (4608T) EPA 817-B-12-002, September 2012, available at https://www.epa.gov/sites/production/files/2015-06/documents/comntainmentanddisposal.pdf • U.S. Environmental Protection Agency, Liberty RadEx National Tier 2 Exercise After Action Reports, For Official Use Only, March 30, 2011. • While not guidance, *per se*, documents retrieved via searching keyword "radiological" under "Key Links" at https://www.epa.gov/homeland-security-research may be informative. • Kaminski, M. D., Lee, S. D., and Magnuson, M. (2016). "Wide-area decontamination in an urban environment after radiological dispersion: A review and perspectives," *J. Hazardous Materials*, 2016, 305: 67-86. Provides a critical review of recommended techniques for performing decontamination in the urban environment based on world-wide experience. Citations contained within exhaustively document the data of method efficacy prior to experience with the Fukushima Daiichi nuclear accident recovery effort. • *Decontamination Report*, Ministry of Environment, Japan, March 2015 (http://josen.env.go.jp/en/policy_document/pdf/decontamination_report1503_full.pdf). Provides a summary of decontamination efforts including basic features of decontamination in Japan; overview of decontamination procedures, management and treatment of removed soil and waste; management of the decontamination project; effects of decontamination; overview, usage and applicable conditions, and verification of effects of decontamination technologies.

TABLE 5-1 (Cont.)

Topic	Resource
Social Media and Apps	• Applications such as Zello may be used to communicate effectively to expedite and coordinate the recovery effort, especially self-help efforts. Zello is an application that emulates "push-to-talk (PTT) walkie-talkies over cell phone networks. The apps are available for Android, iOS, Blackberry, Windows Phone, Windows PC, rugged mobile devices and two-way radios." • The volunteer organization Cajun Navy—founded in 2005 following Hurricane Katrina—is mobilizing rescuers through a channel called "Texas search and rescue." The PTT app lets users send voice messages to different channels. Anyone listening to the channel can hear these messages. People can also talk to each other in private chats. • We may want to research apps or social networking employed during Katrina, Sandy, and Harvey that were used to recruit equipment for cleanup (e.g., dump trucks during Sandy) or rescues (boats during Harvey). Other apps of interest may include FreeCast, Glide, Mumble, and WhatsApp. • Florida State University and the DOE in collaboration with other SMEs developed the Deactivation & Decommissioning Knowledge Management Information Tool (D&D KM-IT). This web-based tool's (https://www.dndkm.org/Default.aspx) objective is to "provide single-point access into the collective knowledge-base of the D&D community within and outside of DOE." It provides searchable information on such areas as technology description and use, best practices, lessons learned, and training related to decontamination and decommissioning of facilities. • The Rad Decon tool found in the RadResponder app (https://www.radresponder.net/#home) helps identify methods for decontamination based on the data primarily found in the UK Recovery Handbooks (https://www.gov.uk/government/publications/uk-recovery-handbooks-for-radiation-incidents-2015).
Developing Programs	The Defense Advanced Research Projects Agency, Defense Science Office (DARPA-DSO) sponsors a program called SIGMA, "Cost-effective, operationally practical, continuous city-scale nuclear and radiological WMD detection capability." 10,000 personal radiation detectors and more than 200 large detectors (vehicle mounted) provide continuous measurements of a city. Scheduled to operationalize wide-area monitoring capability in 2017 (Anne Fischer and Mark Wrobel, Program Managers).

6 CRITICAL INFRASTRUCTURE EVALUATION

The potential implementation of equipment for critical infrastructures was discussed throughout this project. This section summarizes the outcomes from these discussions and information gathering activities. Critical infrastructure is defined by DHS in terms of its relative importance to the stability of numerous sectors in the United States (https://www.dhs.gov/critical-infrastructure-sectors, accessed April 2018): Chemical Sector, Commercial Facilities Sector, Communications Sector, Critical Manufacturing Sector, Dams Sector, Defense Industrial Base Sector, Emergency Services Sector, Energy Sector, Financial Services Sector, Food and Agriculture Sector, Government Facilities Sector, Healthcare and Public Health Sector, Information Technology Sector, Nuclear Reactors, Materials, and Waste Sector, Sector-Specific Agencies, Transportation Systems Sector, Water and Wastewater Systems Sector. The technologies described in the Section 3 tables have been primarily evaluated in the context of roadways, buildings, and open space areas found in the large urban environments of the United States. Within such, aspects of these 16 sectors are included where the needs include addressing affected paved areas, common building materials, vehicles, waterways, and green spaces. However, specific infrastructure may introduce new constraints and variables that have not been addressed. In addition, equipment and capabilities unique to the critical infrastructure may be used during the response and recovery phases to mitigate direct and indirect effects of a wide-area radioactive contamination event. For completeness, a cursory description of specific infrastructure systems is presented below.

6.1 COMMUTER RAIL

Information regarding the public commuter rail infrastructure was presented by the Mass Transit Authority (MTA) of New York City. MTA provided a guidance document entitled "*New York City Transit Grand Central Station Pre-Incident Radiological Dispersal Response and Recovery Plan"* (LLNL-TM-64442, June 28, 2003). In it, a thorough evaluation of the commuter system is presented and a plan "designed to be an operationally focused, hands-on guide to help direct immediate actions to minimize the consequences of a radiological dispersal incident and to facilitate the preparation of a post-incident response and recovery plan and facility-specific strategies to support restoration of [Grand Central Station] service after a radiological dispersal incident." Decontamination strategies used the best techniques and information known to date.

6.2 FREIGHT RAIL

A Regional Environment Manager and Dangerous Goods/Emergency Response Preparedness officer from a Class I, intercontinental, freight rail carrier provided input into this study. Such a large rail carrier has extensive internal resources to ensure continuous operation of their fleet. Some of the techniques that are available in an emergency include:

- Ability to retrofit rail cars and tunnels to add power washing systems for decontamination of engines and rolling stock or to use such systems to decontaminate an inventory of contaminated personal and commercial vehicles.

- Existing rail cars with vacuum units designed to remove debris from the right-of-way.

- Spill control systems for the rail system.

- 20,000-gallon portable tanks.

- Large open spaces along right-of-ways to store or set up unit operations.

- Ballast removal cars.

- Excavators mounted on rail cars.

- Power washing systems for heavily contaminated areas (designed specifically for hazardous cargo in mind).

- Expertise and equipment necessary to set up ad hoc piping systems.

- Expertise and equipment necessary to transport large volumes of liquids from rail cars to fixed storage vessels or from locations off-site into storage vessels on rail.

6.3 WATER SUPPLY

Meetings with experts at public water supply systems were not possible. However, basic information on the unit operations was gathered. Intake of water from fresh water sources such as lakes and rivers commonly incorporate a number of unit operations to ensure the safety of the water supply. These may include chemical treatment (e.g., with activated carbon polyphosphate, chlorine, fluoride, aluminum sulfate and polyelectrolyte), sedimentation, and filtration. Each of these steps accomplishes a different goal, such as eliminating odors, improving taste, killing bacteria, removing micro-organisms and suspended solids, or improving dental hygiene. Additional information about these and other steps can be found in EPA's "Drinking Water Treatability Database" (https://oaspub.epa.gov/tdb/pages/general/home.do).

As an example, the City of Chicago employs a process common to the industry (https://www.cityofchicago.org/city/en/depts/water/supp_info/education/water_treatment.html). The process consists of the following steps: water from Lake Michigan 1) enters the intake tunnel at depths of 20 to 30 feet, 2) passes to the purification plant through a tunnel beneath the lake bed, and 3) is filtered through eight traveling screens to catch coarse debris. Then, the water 4) is pumped up to the first chemical treatment and 5) flows through the chemical application channels. Afterward, 6) it flows through mixing basins where a flocculation process begins. This water 7) passes into settling basins to allow the floc to settle and 8) is filtered through graded sand and gravel beds to clarify the water. Then, the filtered water 9) flows into clear wells and is treated by another chemical application before the finished water 10) enters reservoirs and flows to the distribution system.

Several chemicals are used during the process: chlorine to disinfect the water; aluminum sulfate or an alum and polymer as flocculants; polyphosphates to protect pipes from leaching heavy metals such as lead; activated carbon to remove tastes and odors; and fluoride for dental hygiene. The amount of each added chemical is relatively small (approximately one teaspoon per 100 gallons or 15 parts of chemical to 1 million parts of water).[4]

In view of these types of unit operations, there appears to be opportunities to mitigate the effects of contamination to the water supply. Existing filtration beds may be modified to include selective sorbent material to help remove the contaminants prior to entering the downstream filtration systems. Also, contaminated particulate may be effectively eliminated with existing unit operations although the concentration of radionuclides inside the supply system will require consideration to avoid health hazards associated with elevated radiation fields.

6.4 WASTE WATER TREATMENT PLANTS

Meetings were held with members of the Water Environment Research Foundation (WERF, currently known as the Water Research Foundation), experts at the Metropolitan Water Reclamation District (MWRD) of Greater Chicago, and the Orange County Water District. In the meeting with WERF, it was clearly stated that the wastewater districts were not equipped to handle radioactively contaminated waters. Moreover, they were uncertain as to the effect such waters would have on unit operations, such as the health of the bacterial colonies, and were also unaware of studies predicting the fate of radioactive contaminants in the unit operations. They recommended that water be diverted as much as possible to avoid infiltration into the plant.

Afterward, meetings were held with members of MWRD to discuss Chicago plant operations and potential methods of mitigating the effects of incoming radioactively contaminated waters. With a member of the Orange County Water District, we obtained their opinion of what options might be available in their systems. These are presented below.

Metropolitan Water Reclamation District of Greater Chicago

The MWRD runs typical unit operations to improve wastewater for discharge to the local waterways (Figure 6-1). Discussions included ways to mitigate incoming radioactively contaminated waters. It is possible to divert water from the intake at the reclamation plant and store it in a suitable container for on-site treatment. Also, the MWRD staff explained that they can move incoming water into the Tunnel and Reservoir Plan System (Chicago Deep Tunnel) (https://www.mwrd.org/irj/portal/anonymous/tarp) by causing an overflow of their intake. This can be done by dumping material into the two interceptors (the upstream side of the overflow weirs) leading from the city of Chicago. Then, the water would be diverted into the tunnel system (1.6 billion-gallon capacity in tunnels) and reservoirs (current capacity of 11.4 billion gallons).

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[4] City of Chicago, "Water Management," https://www.cityofchicago.org/city/en/depts/water/supp_info/education/water_treatment.html, accessed June 2018.

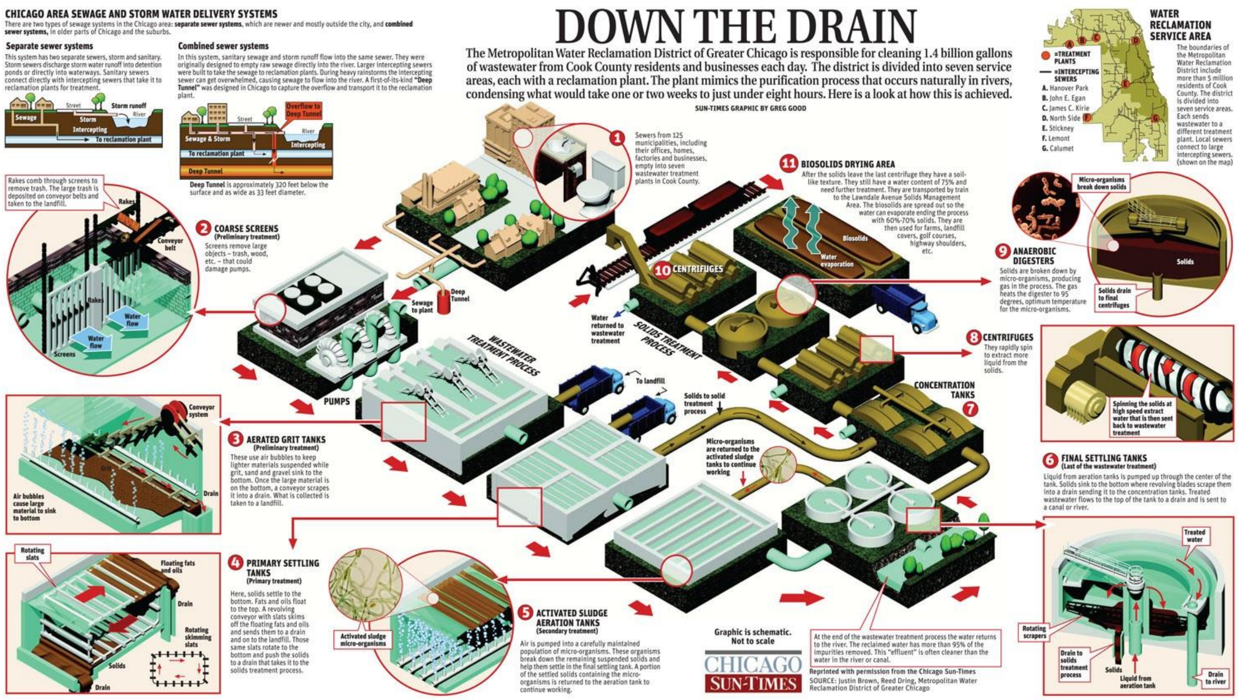

FIGURE 6-1 MWRD Stickney Plant flow diagram. The Stickney Plant is one of seven reclamation plants operated by the MWRD (image courtesy of Metropolitan Water Reclamation District of Greater Chicago).

Once the water is diverted into the tunnels, there may be options to pump and treat the water at the reservoirs or within the tunnel system itself and discharge the treated water back to the reclamation plant. However, the MWRD staff did not recommend dropping solids into the reservoirs to settle the radionuclides and then pump the treated water to the reclamation plant. Instead, to facilitate removal of the radioactive particles and solution, several possibilities were discussed. A sequestration agent (e.g., clay) could be added into the sewer system to react with the contaminated water and sorb the radioactivity onto the clay surface. Then, once the water reaches the reclamation district, the clay can be settled out in the initial unit operations at the plant.

One method might be to add the sequestration agent into sewer inlets on the streets within the contaminated zone and let the slurry mix and react as the flow travels to the reclamation plant. Then, at the plant, the solids are separated. The clean water would eventually discharge to the canal, and the solids would be stored in existing tanks to be treated and/or removed (there is a separate pump station and pipes for removal of these solids).

Another option is to add the sequestration agent directly into the preliminary tanks (settling) and use the primary settlers to be the reactor vessels. The MWRD staff noted that at maximum flow the residence time is 30 minutes, and at low flow periods the rate is 2 hours. Before the primary settler, there is a grit removal tank where some mixing action occurs that can be used to mix the sequestration agents. Adequate space for access by trucks to dump the sequestration agent would need to be established, or the MWRD may employ a conveyer system to meter in the sequestration agents. Figures 6-2 to 6-4 show the unit operations mentioned above for one of the treatment trains at the Stickney facility.

FIGURE 6-2 A look from above the coarse screening operations. Here, the water is agitated via aeration to promote the capture of large debris onto the coarse screens. Sequestering agents can be introduced here via truck or conveyor system and mixed via aeration pumps to promote sorption of radionuclides on the sequestering agents. These finer sequestration agent solids would pass onto the aerated grit tanks.

FIGURE 6-3 Water level view of the aerated grit tanks that can be used to remove the bulk of sequestering agents introduced in the sewer system or in the coarse screen houses. Aeration pumps drive the fluid upward at the right hand side of the photo and cause the fine solids to descend at the left-hand side of the photo to the sloped bottom. The fines collect at the bottom right of the photo, below the aeration pumps. The initially clarified liquid passes to the primary settling tanks.

FIGURE 6-4 Close-up view of the collection trench in a drained aeration grit tank. Note the wood scrapers that drag the fines collected at the bottom of the sloped trench and force them into the collection trench where they are pumped for disposal.

When asked if the District has the ability to divert water directly into the discharge canal before it enters the plant, with the goal being to collect the water in barges located on the canal, the staff explained that they would have to close all gates that lead to the Chicago Deep Tunnel, and then it would overflow as combined sewer overflow. At the plant, they could close the gates inside the plant, then the incoming water would overflow into the canal. However, the outflow pipe into the canal is below the river level, so there is no direct way to isolate and collect that outflow.

Orange County Water District

The representative of the Orange County Water District (OCWD) suggested directing or diverting incoming water using diversion structures currently used to move non-compatible drinking water. One can use a large portable pump that would need to be leased from well flushing or other industry. OCWD was unsure how leased equipment could be decontaminated, or if it were possible. Such water could be sent to the collection system discharge. The OCWD staff raised the concern that there are no current regulations on the biosolids generated from radioactive waters. Therefore, if a radiological release event were to occur, they would rapidly accumulate the biosolids and quickly run out of space.

According to the State of California Proposition 45, the public needs to be notified regarding contents that are being discharged and transported, so developing the appropriate signage might be a potential concern. In addition, if the initial solids are radioactive, then the OCWD might need to re-designate the waste and make appropriate changes to its transport.

When asked if their plant can substitute out their resins systems with selective resins for radionuclides, the OCWD staff explained that their advanced treatment system at the plant has reverse osmosis (RO) membrane units. Perhaps, the radionuclides would be rejected at the RO unit. Beyond the RO, they have an oxidation process. In the large municipal systems, there might be a chance to employ a pillow plug and Baker tanks, trailer or railcar mounted tanks can be used to temporarily hold flow (as a pump-around) and return the water into the system after initial diversion and cleaning.

The OCWD has inflatable tanks/dams that are permanent to the storm water pipe systems (Figure 6-5). It is possible to hold tremendous amounts of water in the concrete lined riverbeds (like Santa Ana riverbed) to treat and then discharge the water. The structures may require decontamination. Some of these lined riverbeds are used for recreation activities, so some provisions would need to be made.

FIGURE 6-5 OCWD inflatable rubber dam spanning the Santa Ana River in Anaheim to divert river water that would otherwise flow to the ocean. The water flows into one of the district's recharge basins, where it eventually percolates into an underground aquifer that supplies water to 2.4 million Orange County residents.

6.5 HOSPITALS

Although we did not have the opportunity to meet with representatives of hospitals, we consulted the *Guidelines for Design and Construction of Hospital and Health Care Facilities* (Facility Guidelines Institute, 2006). Importantly, a common theme in the design of hospitals is the use of non-absorptive surfaces (Figure 6-6) that are durable to physical wear and chemical treatment using cleaning solutions and that minimize the number of joints and joint gaps size. These features should facilitate decontamination of radiological agents.

Ventilation rates in hospitals vary from 2 to 15 air exchanges per hour and 2-3 minimum air changes of outdoor air per hour ("To satisfy exhaust needs, replacement air from the outside is necessary") with directed inflow from the cleanest patient care areas to the less clean areas. Protective environment rooms are protected by HEPA filters at 99.97% efficiency for a 0.3 μm-sized particle. Therefore, airborne contamination entering the ventilation system may or may not pose a hazard depending on the specific air handling systems employed.

FIGURE 6-6 Hospital design and cleanup. Hospitals are designed for facile clean up using common industry practices to minimize transfer of disease. Such practices are compatible with decontaminating radioactive contaminations on surfaces (images courtesy of Shutterstock).

6.6 SEAPORTS

There was no opportunity to consult with representatives at the cargo container ports (Figure 6-7) around the country. However, the surfaces encountered at the port are not unlike those in an urban area. Methods would have to be developed to decontaminate the many cargo containers and manage the radioactive liquid and solid waste. Also, the seaports provide a potential means of transporting large amounts of contaminated debris, provided there is a process to move these materials in accordance with the rules and restrictions for transport of radioactively contaminated materials.

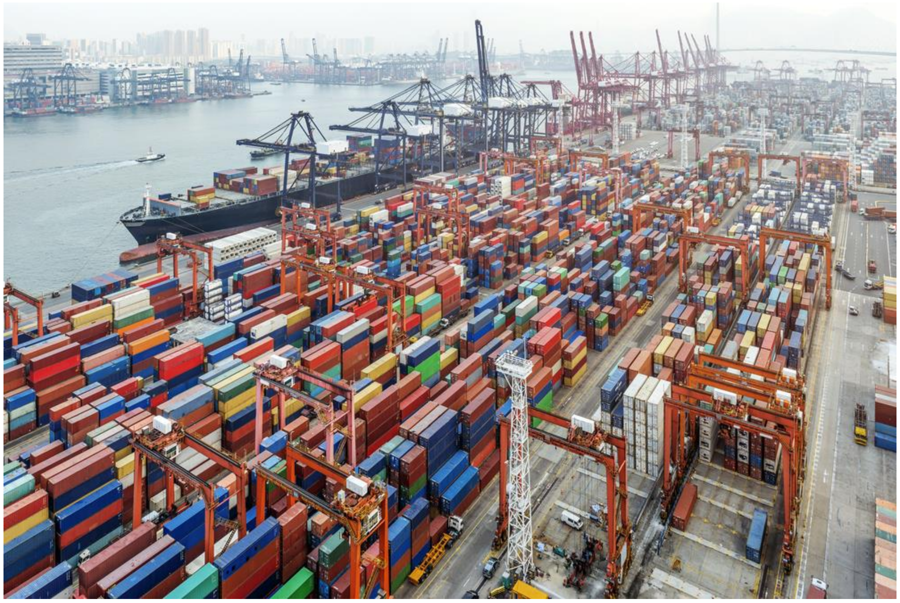

FIGURE 6-7 View of a cargo container port (image courtesy of Shutterstock).

6.7 AIRPORTS

There was no opportunity to consult with representatives at the various airport authorities around the country. We do note that their building and roadway infrastructure (Figure 6-8) is not unlike those found in an urban area. In addition, they have their own emergency capabilities with commensurate equipment assets such as pumps, sprayers, snow and debris removal equipment, and asphalt repair and amendment systems. The large airports often also have direct access to rail and truck transport systems. Therefore, containment of radioactivity and decontamination of the airports may benefit from their own capabilities, assets, and relatively simple design features (i.e., long, flat surfaces). Moreover, the airports provide a means of sending and receiving equipment assets to support a response and recovery effort.

FIGURE 6-8 View of a large international airport located in the United States (image courtesy of Shutterstock).

6.8 ELECTRICAL DISTRIBUTION

No specific subject matter experts were consulted or review of documents related to the infrastructure of electrical distribution (Figure 6-9) was conducted at this time.

FIGURE 6-9 View of electrical distribution substation (image courtesy of Shutterstock).

6.9 NATURAL GAS SUPPLY

No specific subject matter experts were consulted or review of documents related to the infrastructure of natural gas supply was conducted at this time.

6.10 PETROLEUM REFINERY

No specific subject matter experts were consulted or review of documents related to the infrastructure of petroleum refining (Figure 6-10) was conducted at this time.

FIGURE 6-10 View of a petroleum refinery (image courtesy of Shutterstock).

No specific subject matter experts were consulted or review of documents related to the infrastructure of petroleum ocean or river terminals (Figure 6-11) was conducted, although surfaces encountered at the terminals are not unlike those in an urban area.

FIGURE 6-11 View of a large petroleum terminal (image courtesy of Shutterstock).

6.11 INTRA-CONTINENTAL SHIPPING

No specific subject matter experts were consulted or review of documents related to the infrastructure of intra-continental shipping (Figure 6-12) was conducted at this time, although surfaces encountered at the terminals are not unlike those in an urban area. These terminals also provide an integrated network from which to send and receive assets to support a response and recovery effort.

FIGURE 6-12 Views of inland waterway port and rail yard for the movement of intra-continental goods (image courtesy of Shutterstock).

6.12 CRITICAL INFRASTRUCTURE EVALUATION CONCLUSIONS

This exercise of providing a brief evaluation of critical infrastructure shows that many technologies and approaches to mitigating the effects of radioactive contamination developed in Sections 3-4 of this report apply to the structures (e.g., building materials, transport vehicles, water) found in critical infrastructure. Moreover, there is potential to utilize capabilities of critical infrastructure in the radioactive response (e.g., contain water, transport supplies, remove debris) and to design the radioactive response to be most effective given the unique features of the infrastructure itself (e.g., facile decontamination of hospital indoor surfaces, front-end water treatment systems at waste water treatment facilities).

7 CONCLUSIONS

This report provides a thorough evaluation of technologies and equipment assets that may be effective at mitigating the effects of a wide-area radioactive contamination event and to restore critical functions to the urban environment. Moreover, equipment that could facilitate decontamination efforts during a recovery phase are evaluated. The summary of methods has been critically evaluated in terms of equipment availability, potential advantages and limitations, and research needs in order to justify and predict its efficacy. By ranking the host of techniques, a concise list of those technologies is provided that might be most impactful to a response and recovery effort and how to direct future effort. The totality of this effort and future work anticipates providing early responders and stakeholders with practical guidance information to expedite an effective response and recovery effort and mitigate the potentially devastating effects of a wide-area radioactive contamination event.

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